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THE NATIONAL INSTITUTES OF HEALTH RADIATION SAFETY GUIDE

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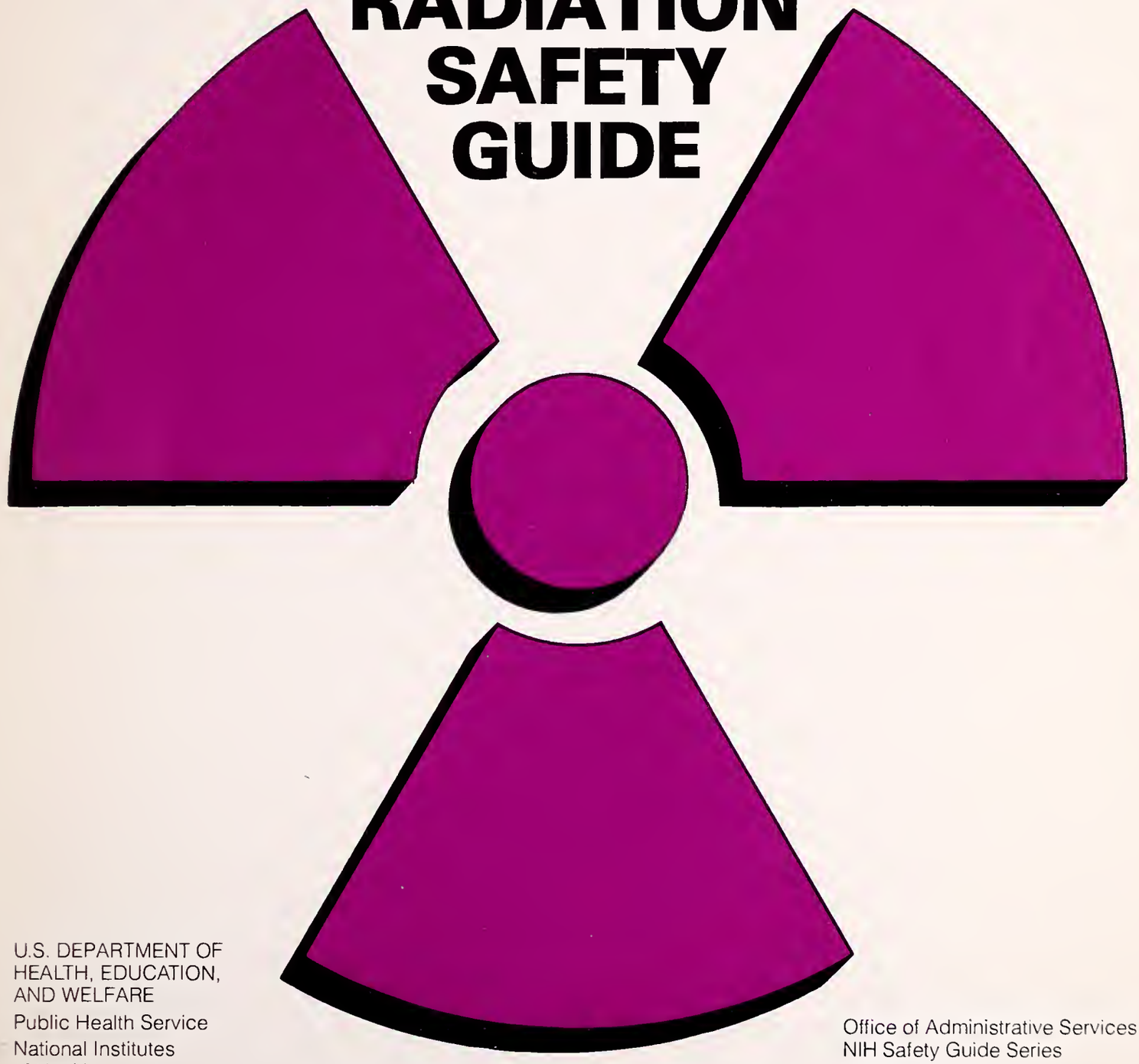
THE NATIONAL INSTITUTES OF HEALTH RADIATION SAFETY GUIDE



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Foreword

The 1979 edition of the NIH Radiation Safety Guide brings up to date the recommendations and requirements governing the use of radiation sources by the NIH Intramural Program.

NIH is using radionuclides in increasing quantities, under a specific license of broad scope issued by the U.S. Nuclear Regulatory Commission. Possession of this license has greatly reduced the detailed problems of radionuclide procurement, but carries strict responsibilities governing use and ultimate disposal. NIH considers the NRC regulations as minimum requirements, and has broadened local controls to include radiation sources not under NRC surveillance.

Recommendations in the 1979 Guide have developed from years of experience in adapting general principles of radiation safety to the NIH environment. The procedures outlined in the Guide are designed to permit the maximum beneficial use of radiation sources with the minimum exposure to patients and personnel. Failure to follow the recommended procedures could result in a serious radiation overexposure, and a suspension or revocation of our license. All personnel using radiation sources are expected to become familiar with the NIH radiation safety requirements and to conduct their operations in accordance with them.

Donald S. Fredrickson, M.D.
Director
National Institutes of Health

Introduction

The National Institutes of Health is authorized to procure and use radioactive materials on the Bethesda reservation under a "specific license of broad scope" issued by the Division of Materials Licensing of the Nuclear Regulatory Commission. This license is contingent upon the existence of a Radiation Committee and a Radiation Safety organization which, among other requirements must:

1. Assure that any investigator using radioactive materials is qualified by training and experience, has the facilities to handle the materials safely, and proposes a use which is safe to all concerned.

2. Assure observance of all safety standards established by the Nuclear Regulatory Commission, National Council on Radiation Protection and Measurements, and other regulatory or standards setting agencies.

3. Keep records of the receipt, storage, use, transfer, and ultimate disposal of all radionuclides used at NIH.

4. Keep records of the monitoring of personnel and areas involved in the use of radionuclides and other sources of ionizing radiation.

NIH is subject to periodic inspections by the Division of Regulatory Operations of the Nuclear Regulatory Commission to insure that all requirements of the license are being met. These inspections are very thorough, including monitoring checks of laboratory areas, inspection of procurement and disposition records, records of the qualifications of individual users, and records of administrations to patients. Violations of license requirements can result in a loss of the license.

All sources of ionizing radiation are not covered by the Nuclear Regulatory Commission license. These sources are, however, controlled by

regulations issued by the Director, NIH, upon recommendation of the Radiation Committee. Non-license sources include x-ray machines, high voltage accelerators, electron microscopes, and radioactive materials from sources other than reactor by-products.

This Guide describes rules and procedures required of NIH under the terms of NRC licensure, and for the use of non-licensed ionizing radiation sources as set forth by NIH regulations.

In total, the 1979 revision of the NIH Radiation Safety Guide represents several decades of intramural experience. Additionally, it reflects authoritative standards, guidelines, recommendations and research data concerning physical aspects and bioeffects of ionizing radiation obtained from the scientific literature.

Previous editions of this Guide included a reasonably comprehensive bibliography of the most important of these sources; the literature is now so extensive, however, that it is not feasible to include even a highly selective bibliography. Therefore, readers who desire documentation for any particular policy, procedure or quantitative data contained in these pages are invited to communicate directly with the NIH Radiation Safety Office.

Although intended primarily for NIH personnel engaged in intramural laboratory and clinical investigation, past experience has shown the existence of a considerable external demand for copies of this Guide. To accommodate this demand more effectively, arrangements have been made with the U.S. Superintendent of Documents to place on sale single and bulk copies of the 1979 edition of the NIH Radiation Safety Guide.

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National Institutes of Health Radiation Protection Guide

Ionizing radiation is among the most versatile and useful tools of modern medicine and biomedical research. Like many other instrumentalities of medicine and research, ionizing radiation is potentially hazardous unless used with strict adherence to safety rules and procedures.

The risk of unguarded exposure to ionizing radiation includes the possibility of damage to future generations. Thus the safety rules which govern all uses of ionizing radiation are as concerned with preventing genetic damage as with protecting the health of the exposed individual. When followed faithfully, these rules limit exposures of radiation workers to levels far below those which might cause any adverse somatic or genetic effects.

The rules and procedures set forth in this Guide have one single, straightforward purpose—to protect NIH patients and employees against unnecessary and potentially harmful radiation exposure.

Four stages of group and individual responsibility are involved in the radiation safety program. All are equally important:

Radiation Committee: this is a high-level group of physicians and scientists appointed by the NIH Director to establish policies and regulations governing the use of ionizing radiation in NIH intramural programs.

Radiation Safety Office: an operating group of trained health physicists and technicians which is responsible for NIH-wide compliance with these policies and regulations; it also provides a variety of technical services necessary to achieving such compliance.

Individual Users: physicians, scientists, other professionals, as well as technical and other workers engaged in patient care, clinical and laboratory research, and research support activities which involve actual use and handling of materials and devices producing ionizing radiation. These personnel usually work under the immediate supervision of Authorized Users.

Authorized Users: physicians and laboratory scientists whose training and experience are such that they have been authorized by the Radiation Committee to use ionizing radiation in their clinical care, clinical research, and laboratory research activities.

In the following pages detailed descriptions are given of the responsibilities of each of these four categories. Information is also provided on policies, rules and procedures for various particular aspects of ionizing radiation source procurement and usage. Careful observance of responsibilities, rules and procedures set forth in this Guide will insure adequate protection against unnecessary exposure to ionizing radiation.

Radiation Committee Responsibility

The Radiation Committee is composed of ten members appointed by the Director, NIH. The membership consists of one group of five physicians who are nominated by the Medical Board and, in conformity with NRC recommendations, is made up of one hematologist, one radiologist, one pathologist, one internist, and one physician with broad background in the use of radionuclides. A second group of four scientists is nominated by the Scientific Directors. At least one of these scientists is to be a radiation physicist with training and experience in health protection. The Chairman of the Radiation Committee, the Radiation Safety Officer, and a representative of the Office of the Director are appointed by the Director, NIH. The Committee shall have jurisdiction over radiation sources and activities in areas under NIH control, including intramural program off-site use.

Functions

(a) Recommend policies regarding patient and plant radiation safety to the Director, NIH.

(b) Provide technical advice to the Radiation Safety Officer on matters regarding radiation safety.

(c) Receive, review, and act on all applications for the use of radiation sources in any areas used by

NIH personnel. These sources include radionuclides to be used in human subjects.

(d) Receive and review periodic reports from the Radiation Safety Officer on monitoring, contamination, and personnel exposure.

(e) Periodically review the overall use of radiation sources at NIH from the standpoint of operational hazards.

(f) Review all instances of alleged infraction of use and safety rules with the Radiation Safety Officer and the responsible Clinical and Scientific Directors before submitting reports or recommendations to the Director, NIH.

Radiation Safety Office Responsibility

The Radiation Safety Office, under the direction of the NIH Radiation Safety Officer, is responsible for:

1. General surveillance of all health physics activities, including both personnel and environmental monitoring.

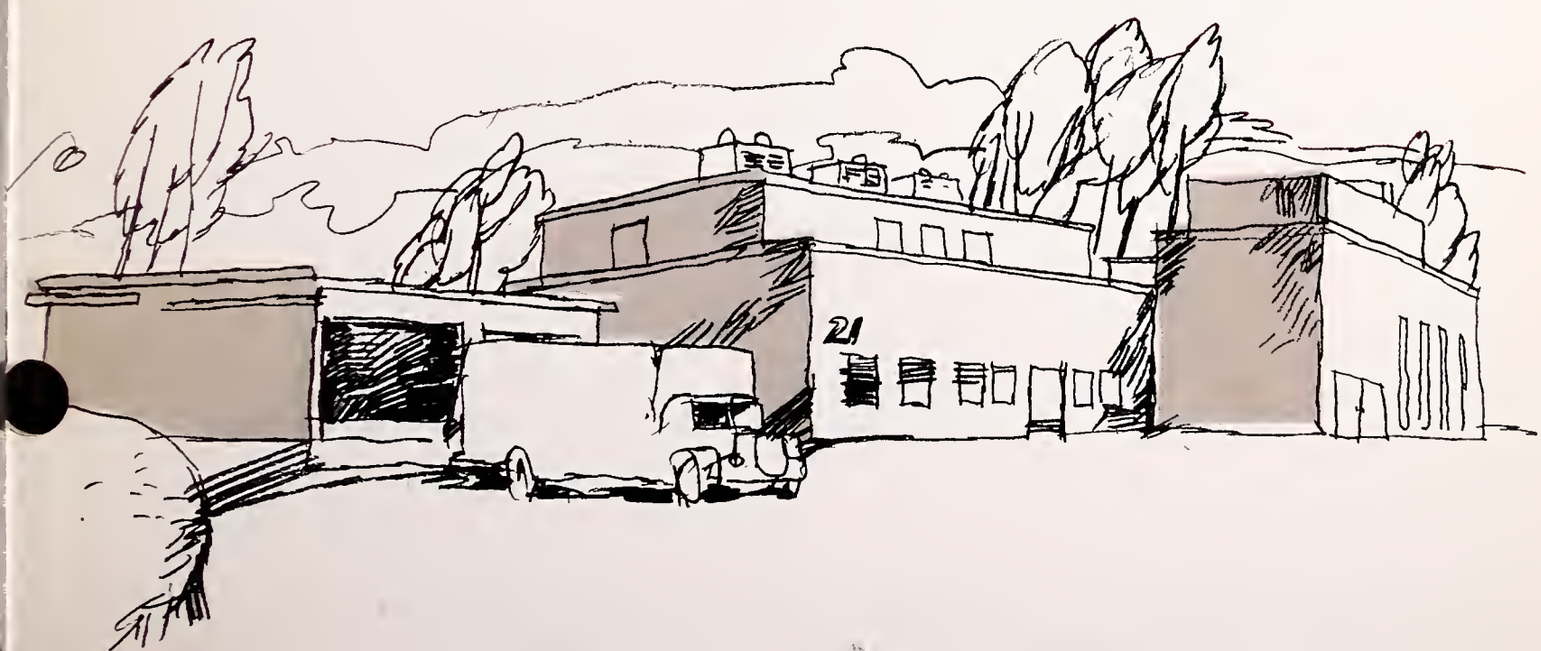
2. Furnishing consulting services to personnel at all levels of responsibility on all aspects of radiation protection.

3. Receiving, delivering, and shipping all radioactive materials coming to or leaving the NIH reservation.

4. Assaying and performing radionuclidic purity checks on all radioactive materials to be used in humans for therapeutic purposes.

5. Monitoring all accelerators and other machines capable of producing penetrating radiations. Calibrating the output of these machines as requested.

6. Distribution and processing of personnel monitoring equipment including the keeping of records of internal and external personnel exposure, and notifying



individuals and their supervisors of exposures approaching the maximum permissible amounts and recommending appropriate remedial action.

7. Instructing personnel in proper procedures for the use of radioactive materials.

8. Supervision and coordination of the waste disposal program, including the keeping of waste storage and disposal records.

9. Operation of and the allocation of space in the Radionuclide Laboratory, Building 21. This laboratory is equipped for the handling of high levels of activity. Space is available in this laboratory to all NIH workers on an allocation basis. Non-tracer level radionuclide work will be done in this building unless the Radiation Committee grants approval to do the work elsewhere.

10. Storage of all radioactive materials not in current use.

11. Performing leak test on all sealed sources.

12. Maintaining a periodic inventory of all radioactive materials on the NIH reservation.

13. Supervising decontamination in cases of contaminating accidents.

14. Maintaining a continuous program of environmental radiation hazard evaluation and hazard elimination.

Individual User Responsibility

Each individual at NIH who has any contact with radioactive materials is responsible for:

1. Keeping his exposure to radiation as low as possible, and specifically below the maximum permissible exposure as listed in the following table:

Rems per calendar quarter	
Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1 1/4
Hands and forearms; feet and ankles	18 3/4
Skin of whole body	7 1/2

Also see additional guidelines for maximum permissible doses, e.g., for fertile aged women and the fetus on page 74.

Laboratory air and water concentrations shall be maintained below the levels listed in the Code of

Federal Regulations, Title 10, Part 20 (10 CFR 20) "Standards for Protection Against Radiation." (See Appendix)

2. Wearing the prescribed monitoring equipment such as film badges and pocket dosimeters in radiation areas. Personnel who work only with pure alpha emitters or only with pure beta emitters having a maximum energy of less than 0.2 MeV will not be required to wear film badges.

3. Surveying his hands, shoes, and body for radioactivity, and removing all loose contamination before leaving the laboratory to smoke, eat, etc.

4. Utilizing all appropriate protective measures such as:

(a) Wearing protective clothing whenever contamination is possible, and not wearing such clothing outside of the laboratory area.

(b) Wearing gloves and respiratory protection when necessary.

(c) Using protective barriers and other shields whenever possible.

(d) Using mechanical devices whenever their aid will assist in reducing exposure.

(e) Using pipette filling devices. *Never pipette radioactive solutions by mouth.*

(f) Performing radioactive work within confines of an approved hood or glove box unless serious consideration has indicated the safety of working in the open.

5. Avoiding smoking or eating in radionuclide laboratories. It is recommended that eating be done in the cafeterias whenever possible. Smoking or eating may be permitted in an office area of a laboratory that has been demonstrated to be free of contamination. Refrigerators shall not be used jointly for foods and radioactive materials.

6. Maintaining good personal hygiene.

(a) Keep fingernails short and clean.

(b) Do not work with radioactive materials if there is a break in skin below the wrist.

(c) Wash hands and arms thoroughly before handling any object which goes to the mouth, nose, or eyes.

7. Checking the immediate areas, e.g., hoods, benches, etc., in which radioactive materials are being used, at least once daily for contamination. A log record should be maintained of these surveys including results which are entirely negative. Any contamination observed should be clearly marked and the Radiation Safety Office notified.

8. Keeping the laboratory neat and clean. The work area should be free from equipment and materials not required for the immediate procedure. Keep or transport materials in such a manner as to prevent breakage or spillage (double container), and to insure adequate shielding. Wherever practical, keep work surfaces covered with absorbent material, preferably in a stainless steel tray or pan, to limit and collect spillage in case of accident.

9. Labeling and isolating radioactive waste and equipment, such as glassware, used in laboratories for radioactive materials. Once used for radioactive substances, equipment should not be used for other work, and *shall not be sent from the area to central cleaning facilities, repair shops, or to surplus, until demonstrated to be free of contamination.*

10. Requesting Radiation Safety office supervision of any emergency repair of contaminated equipment in the laboratory by shop personnel or by commercial service contractors. At no time shall servicing personnel be permitted to work on equipment in radiation areas without the presence of a member of the laboratory staff to provide specific information.

11. Reporting accidental inhalation, ingestion, or injury involving radioactive materials to his supervisor and the Radiation Safety Office, and carrying out their recommended corrective measures. The individual shall cooperate in any and all attempts to evaluate his exposure.

12. Carrying out decontamination procedures when necessary, and for taking the necessary steps to prevent the spread of contamination to other areas.

13. Complying with requests from the Radiation Safety Office for body burden measurements in the whole body counter and the submission of urine samples for radioassay. Requests for these tests will be made in the case of workers using significant quantities of both γ and β emitters.

Authorized User Responsibility

Authorized users are responsible for insuring that the preceding individual responsibilities are discharged by those under their control, and are further responsible for:

1. Adequate planning. Before an experiment is performed, the supervisor should determine the types and amount of radiation or radioactive material to be used. This will generally give a good indication of the protection required. The procedure must be well outlined. In many cases, before the procedure is actually performed with radiation, it should be rehearsed so as to preclude slip-ups or unexpected circumstances. In any situation where there is appreciable radiation hazard, the Radiation Safety Office shall be consulted before proceeding.

2. Instructing those employees for whom they are responsible in the use of safe techniques and in the application of approved radiation safety practices and insuring attendance in required radiation safety courses.

3. Furnishing the Radiation Safety office with information concerning individuals and activities in their areas—particularly, pertinent changes in their personnel rosters.

4. Contacting the Radiation Safety Office whenever major changes in operational procedures, new techniques, alterations in physical plant (e.g., the removal of radiochemical fume hood), or when new operations which might lead to personnel exposure are anticipated.

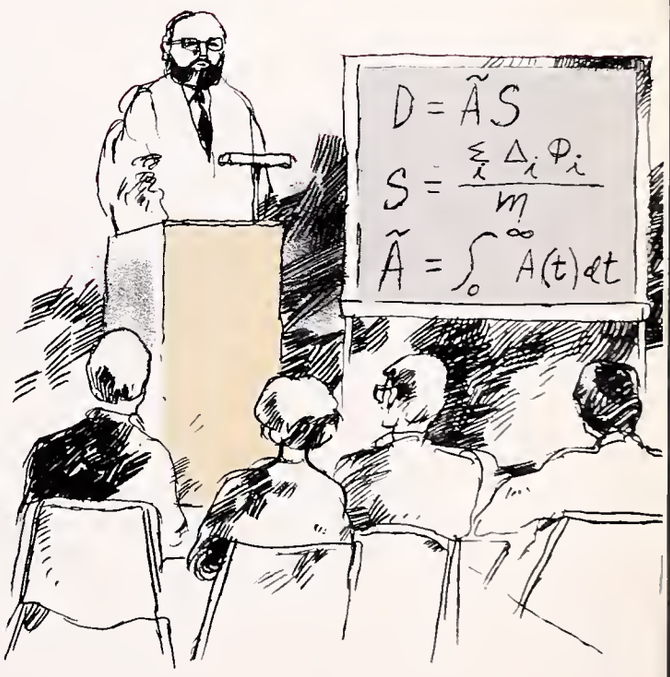
5. Complying with the regulations governing the use of radioactive materials, as established by the NRC and the NIH Radiation Committee, for:

(a) Correct procedure for the procurement of radioactive materials by purchase or transfer. (See procedure for Procurement of Radiation Sources.)

(b) Posting areas where radionuclides are kept or used, or where radiation fields may exist.

(c) Seeing that each sign carries the name of the personnel currently responsible for the associated area.

(d) Recording the receipt, transfer, and disposal of radioactive materials in his area. This includes sealed sources such as ion sources in gas chromatographs and static eliminators. The authorized user must be prepared to submit semiannually the required inventory data upon request.



(e) Assuring that all radioactive waste materials are consigned to the Radiation Safety Office for disposal.

(f) Taking steps to prevent the transfer of radioactive materials to unauthorized individuals. This includes the proper disposition of radioactive materials possessed by terminating workers.

6. Keeping stocks of stored radioactive materials to a minimum within laboratory areas. Authorized users should employ the storage facilities of the Radionuclide Laboratory, Building 21, for shipments not needed in current research.

7. Complying with proper procedure for termination of employment or termination of any experiment using radioactive materials. The authorized user is reminded that, under the terms and conditions of the NRC-NIH license, he must return to the Radiation Safety Office all radioactive materials, including waste, assigned to him under the license. Particular care should also be exercised to see that specialized equipment such as personnel monitoring devices (e.g., film badges), survey instruments, and shielding materials are returned to the Radiation Safety Office. A final termination survey should also be requested by telephone.

Policies and Procedures for Radionuclide Areas

In addition to the Code of Federal Regulations, Title 10, Parts 19 and 20, as appended to the Guide, the following policies and procedures will apply to the NIH license:

1. Proper Marking of Laboratories, Areas, and Equipment

(a) A "CAUTION RADIOACTIVE MATERIALS" sign must be conspicuously posted on the doors to laboratory areas where radioactive materials are being used or stored. The name and home phone number of the individual responsible for the posted area shall be shown in the designated place on the sign in order to facilitate contact in case of emergency. The supervisor shall be responsible for seeing that the posted information is current. The signs must not be removed from any room except by Radiation Safety personnel following an inspection survey.

(b) Storage areas shall be conspicuously marked with a "CAUTION RADIOACTIVE MATERIALS" sign. In addition, containers in which materials

are transported or stored shall bear a durable, clearly visible label bearing the radiation caution symbol and the words "CAUTION RADIOACTIVE MATERIALS." This label shall also state the quantities and kinds of radioactive materials in the containers and the date of measurement of the quantity.

(c) Radiation areas in the laboratory, i.e., areas where radiation levels might expose individuals to 5 millirem in any one hour; or in any five consecutive days, a dose in excess of 100 mrem, shall be posted with the sign "CAUTION RADIATION AREA."

(d) All equipment contaminated with radioactive material shall be marked with signs, decals, or other conspicuous means. Labeling shall not be required for laboratory containers such as beakers, flasks, and test tubes, used transiently in laboratory procedures during the presence of the user.

(e) All signs referred to in this part are available from the Radiation Safety Office, Building 21.

2. Shielding of Sources

(a) Radioactive sources or stock solutions in the laboratory shall be shielded in such a manner that the radiation levels in any occupied area will not expose individuals in the area to more than 100 mrem in any five consecutive days.

(b) Various shielding materials are available on loan from the Radiation Safety Office.

3. Aerosols, Dusts, and Gaseous Products

(a) Procedures involving aerosols, dust or gaseous products, or procedures which might produce airborne contamination shall be conducted in a hood, dry box, or other suitable closed system.

(b) All releases from such systems shall not exceed the maximum permissible concentration in air for the nuclide in question. See Appendix B, Table II of 10 CFR 20 for appropriate values. However, where practical, traps should be incorporated in the experimental set-up to insure that environmental releases are as low as possible.

(c) Radioactive gases or materials with radioactive gaseous daughters must be stored in gas-tight containers and must be kept in areas having approved ventilation.

(d) Hoods to be used for radionuclide work should be tested by the Environmental Services Branch,

DRS, to insure that they meet the minimum requirements for air velocity at the face of the hood.

4. Sealed Radioactive Sources

(a) All sealed radioactive sources must be shipped to: Radiation Safety Officer, National Institutes of Health, Building 21, Radionuclide Laboratory, Bethesda, Maryland 20014. Each source must be registered with this office.

(b) For those sources which may change location frequently, the Radiation Safety Office in cooperation with individual users shall establish strict accountability procedures.

(c) Sealed sources shall be leak tested by Radiation Safety personnel prior to initial use and at least every six months thereafter.

5. Radioactive Materials in Gas Chromatography Equipment

All gas chromatography units in which radioactive materials are to be used are regulated as follows:

(a) As is true with other radioactive shipments, radioactive foils to be used in gas chromatography cells must be shipped to: Radiation Safety Officer, National Institutes of Health, Building 21, Radionuclide Laboratory, Bethesda, Maryland 20014. Each foil must be registered by number with this office.

(b) In addition, each cell containing a radioactive foil must have a label showing:

The radiation caution symbol with the words "CAUTION RADIOACTIVE MATERIAL"; and

The identity and activity of the radioactive material.

The radioactive foil shall not be removed from its identifying cell except for cleaning and shall not be transferred to other cells.

(c) The following notice shall appear in a conspicuous location on the outside of each gas chromatography unit: "This equipment contains a radioactive source registered with the NIH Radiation Safety Office as required by license from the Nuclear Regulatory Commission. Notify the Radiation Safety Office before removing the source from this room or area, or upon any change in custodial responsibility." These notification tags are available from the Radiation Safety Office, Building 21.

(d) Individuals using radioactive components in gas chromatography equipment must vent the cell-exhaust through plastic tubing into a hood, room exhaust, or Radiation Safety approved trap, to avoid contamination of work areas from the release of radioactive tagged samples introduced into the system or from the accidental overheating of radioactive foils in the cells.

(e) The Radiation Safety Office will perform periodic leak tests, store radioactive foils when not in use, and maintain the necessary records on such tests and storage.

6. Work Surfaces

All work areas (bench tops, hood floors, etc.) as well as storage areas and areas adjacent to permanent set-ups and sinks should be covered at all times with stainless steel or plastic trays, uncracked glass plates, or other impervious materials. For some purposes a plastic-backed absorbent paper (e.g., "Kimpak", available from the Central Storeroom) will be satisfactory. However, if such paper is used, it should be discarded frequently to prevent radioactive materials from dusting off the surface.

7. Periodic Surveys of Radiation Areas

The immediate areas (e.g., hoods, bench tops) in which radioactive materials are being used should be checked for contamination at least once daily by the radiation workers in that laboratory. In addition, these areas should be inspected each and every time there is reason to suspect a contamination incident. *Records shall be kept on both positive and negative survey results in the authorized user's laboratory logs.*

8. Laboratory Monitors

Each laboratory or area (other than those where ^{3}H is used exclusively or where only exempt quantities of other radionuclides are handled) shall be equipped with a portable or semiportable monitoring device to be used for personnel and area monitoring. Laboratory monitors of this type are available on loan from the Radiation Safety Office.

9. Removal of Equipment from the Laboratory

Once used for radioactive substances, equipment shall not be used for other work, or sent from the area to central cleaning facilities, repair shops, surplus, or returned to the source of supply, until demonstrated to be free of contamination. Equip-

ment to be removed from the Radionuclide Laboratory, Building 21, must be cleared through the Radiation Safety Office.

10. Repair and Maintenance of Equipment in the Laboratory

Equipment to be repaired by shop and maintenance personnel, or by commercial service contractors, shall be demonstrated to be free of contamination prior to servicing. If it becomes necessary to make emergency repairs on contaminated equipment, the work will be supervised by a member of the Radiation Safety Office staff, who will assure that the necessary safeguards are taken. It is the responsibility of the laboratory personnel to request this supervision from the Radiation Safety Office.

11. House Vacuum Lines

House vacuum lines are vulnerable to contamination. If house vacuum lines are to be used, the withdrawn gas must be demonstrated to the Radiation Safety Office to be free of radioactivity. It is advisable to use a separate vacuum system whenever possible, such as a separate vacuum pump exhausting into a hood.

12. Radioactive Contamination of Areas

In general, no radioactive contamination can be tolerated. Exceptions to this will include certain hood trays, dry boxes, stainless steel trays, Kimpak covered surfaces, or other equipment which is used frequently for active work and which will be clearly marked with the standard radiation caution signs or stickers. Any contamination that is not confined to protected surfaces should be reported immediately to the Radiation Safety Office. The Radiation Safety staff will supervise the decontamination of such areas or equipment.

13. Decontamination of Areas Contaminated with Radioactivity

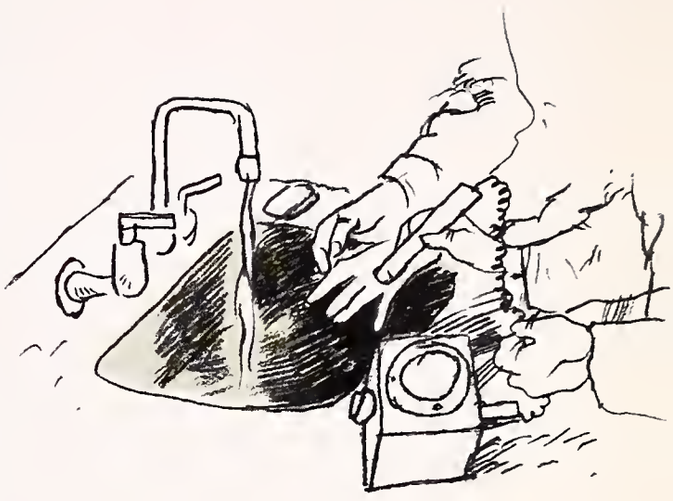
Preparations for decontamination should be begun promptly. Determine the extent and hazard of contamination. The Radiation Safety Office staff will assist in this evaluation. The individual responsible for the contamination will be expected to do most of the cleanup under the supervision of the Radiation Safety staff. After decontamination, the area or equipment shall be considered contaminated until proved otherwise by the Radiation Safety Office.

14. Decontamination of Personnel Contaminated with Radioactivity

(a) Notify supervisor immediately after contaminating accident.

(b) Wash body area involved thoroughly for 2 or 3 minutes, repeatedly "soaping" and rinsing. Consideration should be given to the chemistry of the contaminant and an attempt made to find a suitable agent for dissolving it. Any cleansing agent may be used, but synthetic detergents are preferred to soaps. Avoid prolonged use of any one decontamination procedure. Irritation of the skin may impede the success of more suitable procedures. Avoid the use of organic solvents. They may make the skin more permeable to radioactive contaminants.

(c) If this procedure is not immediately and completely effective, notify the Radiation Safety Office and proceed at once to the Medical Officer in charge of the Building 10 Health Unit, Occupational Medicine Service. Special decontaminating agents such as "Versene", "Radiacwash", etc. may be used under the direction of the Medical Officer.



15. Prophylactic Thyroid Blocking Agents in Laboratories Using Radioiodine

Individuals utilizing greater than 10mCi radioiodine should consult with and follow the recommendations of the Occupational Medical Service prior to the use of prophylactic thyroid blocking agents. Such individuals are reminded that the use of these blocking agents in no way reduces the need to take all other precautions in the safe handling of radioiodine.

Radioactive Waste

No radioactive wastes shall be disposed of by conventional methods. This means particularly that solid wastes may not be placed in the standard waste containers to be collected by housekeeping personnel, and that liquid wastes may not be discharged into the sewer. Animals must not be incinerated in the general purpose incinerator.

No radioactive waste shall be released from a laboratory area for pickup and disposal prior to autoclaving or otherwise suitable deactivation of infectious agent(s). Radioactive waste disposal procedures in the waste handling area of the Radionuclide Laboratory,

Building 21, involve crushing and compacting of dry wastes by compaction devices and pooling of liquids in approved shipping containers for disposal by a licensed contractor. These procedures are not compatible with the proper handling of infectious agents. Similar considerations shall also be given to other highly toxic or hazardous substances. (See Section 3)

1. Waste Containers

To insure that solid and liquid wastes are kept separate, each laboratory having radioactive waste must be equipped with at least one container for solid dry waste and one for liquid waste. Due to the methods of ultimate disposal of waste by the Radiation Safety Office, short half-life (less than 30-days) waste must be kept separate from long half-life waste. Additional waste containers shall be requested for this purpose and marked as to the radionuclides being used.

(a) Solid dry waste containers. These may be obtained from the Radiation Safety Office. They must be kept fitted with a disposable waterproof polyethylene liner.

(b) Liquid waste containers. Plastic carboys, glass jars, or bottles are suitable for storage of liquid wastes. If the liquid waste container is glass or ceramic, then it must be kept in such a manner that if accidentally broken, the contents will be retained in a small area, e.g., having it set in a large pan. These liquid containers must possess securely fitting covers or corks, and must be kept closed. In addition, they shall be conspicuously marked with appropriate radiation signs.

(c) Animal carcasses. Small radioactive animals should be placed in the standard polyethylene bags. Larger animals (dogs, etc.) should be placed in large polyethylene bags which will in turn be placed in a cardboard container (NIH Stock No. 4–0870). Each unit must be conspicuously

marked with a "CAUTION RADIOACTIVE MATERIAL" sign and in addition, the radionuclide(s) and amount remaining in the carcass shall be posted on the bag or label. If pickup cannot be arranged within 4 hours of sacrifice of animals, such animal carcasses must be refrigerated or preferably frozen.

(d) Liquid scintillation vials. All liquid scintillation vials must be disposed of as radioactive waste. Prior to removal, all liquid scintillation vials must be tightly capped and returned to the original shipping trays.

2. Waste Pickup

Request for removal of liquid and dry waste may be made by telephone to the Radiation Safety Office. At the time of the telephone request and at the time of pickup, the investigator must be able to estimate, with a fair degree of accuracy, the amount of radioactive waste in each container.

3. Unusual Waste Disposal Problems

Plans for proper disposal of infectious agents or highly toxic or hazardous substances shall be made early in the design stage of the experiment.

Proposed procedures involving unusual waste disposal problems will be considered individually by the Radiation Committee or the Radiation Safety Officer and staff.

Physician's Responsibility and Procedures

In carrying out the responsibilities and duties assigned it by the NRC under the Broad License and by the Director, NIH, the Radiation Committee requires compliance with the following policies and procedures:

1. Experience and Training of Applicants

The Committee is bound by the requirements of NRC for training and experience of physicians in the use of radioactive materials. These requirements are listed in "Nuclear Regulatory Commission Licensing Guide—Medical Programs." Copies of this report are available for reference from both the Radiation Committee office and the Radiation Safety Office.

2. Procedures for Making Application to the Committee

A separate application is required for each project which contemplates the use of radioactive materials

in humans. This application must include:

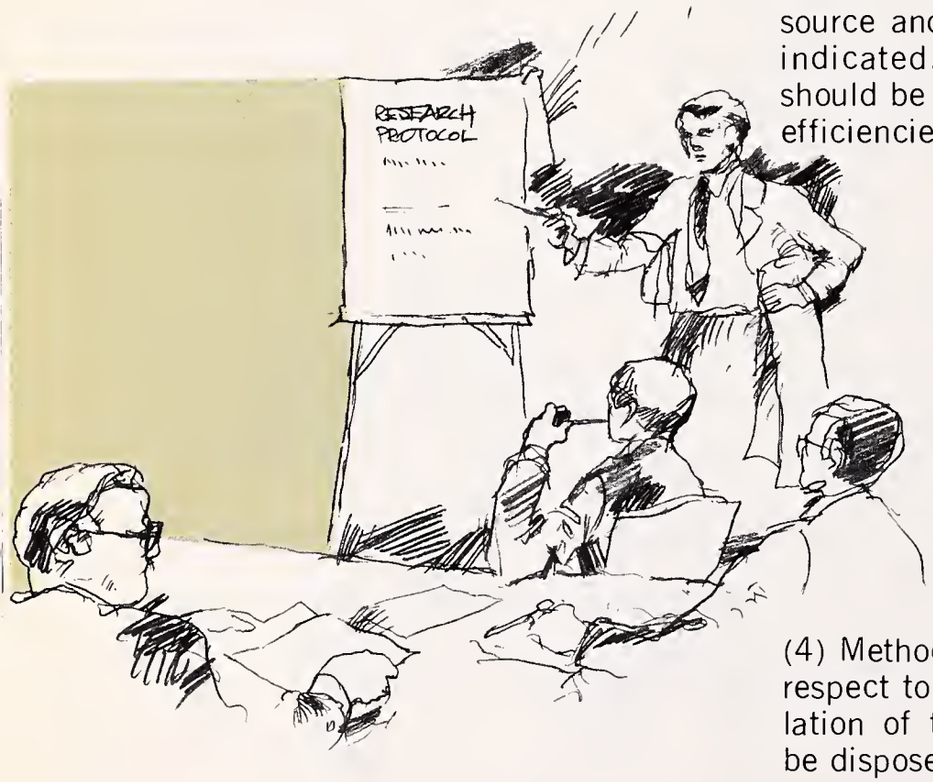
(a) Form NIH–88–23 : A self-explanatory form available from the Chairman, Radiation Committee.

(b) Narrative description of project which shall include:

(1) Title of the project.

(2) A statement of the purpose and justification for the use of radionuclides.

(3) Description of the project; including methods, characteristics of radioactive materials (half-life, nature and energy of emissions, modes of decay), details of doses (single and total) and the anticipated results. Reference to previous work published by the applicant or others concerning animal experimentation or human use (including doses) should be carefully documented. The Committee requires a clear, concise calculation of the anticipated whole body and critical organ absorbed dose in rads, stating the period of such exposure and radiation hazards, if any. Include uptake and excretion data. The formula used for such calculation should be clear, all terms defined, and the source and estimated reliability of the formula indicated. Assumptions used for estimates should be stated. Assay methods and estimated efficiencies should be given.



(4) Methods of waste disposal, particularly with respect to urine, stools, exhaled air, and calculation of the daily amounts of radioactivity to be disposed of into the sewer or air, if any.

(5) Safety precautions which will be initiated to protect the patient, other patients in the vicinity of the radioactive patient, and the patient-care staff and adjunct personnel.

(6) If the use of the radioactive material is planned for normal human subjects, the application must specify minimum ages of these subjects, the fact that they are volunteers, cognizant of the possible radiation hazards, and the status of such normal subjects with respect to other contacts with radiation, and cumulative exposure. In addition, the Radiation Committee requires a short statement from the investigator regarding the information he would supply to the volunteer pursuant to obtaining his consent.

(c) With the first application from each investigator, a complete description of his training and experience, stating periods, location and supervision in the use of radionuclides (Form NIH-88-2, NIH-88-24).

Upon completion, this application should be forwarded through the Branch Chief, and the Clinical Director of the applicant's Institution to the Chairman of the Radiation Committee. Action of the Committee will be returned through channels to the applicant and copies will be forwarded to the Radiation Safety Officer and to the Chief, Radiopharmaceutical Section. The signed approved original will constitute the investigator's authorization under the Broad NRC License to procure and use the materials. Physicians may obtain information on current approved investigators and specific medical uses at NIH from the Radiation Committee office.

Should questions arise in the Committee regarding details of an application, the investigator will be invited to meet with the Committee and discuss the details of his proposal. Should the Committee finally disapprove the application on the basis of conflict with restrictions of the NRC or Director, NIH, or Committee policies, the application nevertheless will be forwarded to NRC for its review and action upon further recommendation of the investigator and his Clinical Director.

Each authorization will be marked with an expiration date which will usually be the last day of the month, one year after the month of the approval. Authorized investigators should anticipate the expiration of their approvals by at least one month and apply for renewal of the authorization. For this purpose, it is necessary to submit only the Form NIH–176 (without narrative description) and a "Summary of Use of Radioactive Materials," Form NIH-88-25. The investigator should

clearly state that this is an application for renewal of the previous authorization without modification, and should include the number of the original authorization and date.

If an investigator has no positive plans for the use of a given authorization during the coming year, he should consider its retirement in order to save on bookkeeping in the Radiation Committee, Radiation Safety and Radiopharmacy offices. Such a retired authorization can usually be reactivated by the Chairman, Radiation Committee, in one day should need for it develop.

An authorization which is being considered for renewal and which reflects frequent patient use may be retained and established as a service to be provided to the clinician and patient by the Department of Nuclear Medicine. Decision to provide this service will reside with the Chief, Department of Nuclear Medicine. This service consideration would also be applied in the situation where several similar authorizations by separate applicants reflect an overall need for patient service from various areas of the Clinical Center.

After receiving the approved Form NIH-88-23, the investigator should comply with the procedures "Procurement of Radiation Sources" listed elsewhere in this Guide.

3. Responsibility

The authorized investigator has primary responsibility for the use of the radioactive material; for the protection of the patient, and for the safe handling of any material removed for study. The Radiation Safety staff is responsible for the protection of the patient-care staff, for instructions needed to insure radiation-safe conditions, and for the handling of contaminated materials, equipment, and waste. *Any delegation of work does not shift responsibility.*

Special instructions regarding patient treatment shall be on Clinical Record SF–508. Radiological safety precautions will be recorded on Form NIH–88-7.

4. Justification

The widely accepted policy for medical uses of radionuclides is that radioactive substances should never be used in humans except when the investigation or treatment justifies the risk involved. It is NIH policy to encourage use of the most sensitive instrumentation and assay procedures available, and

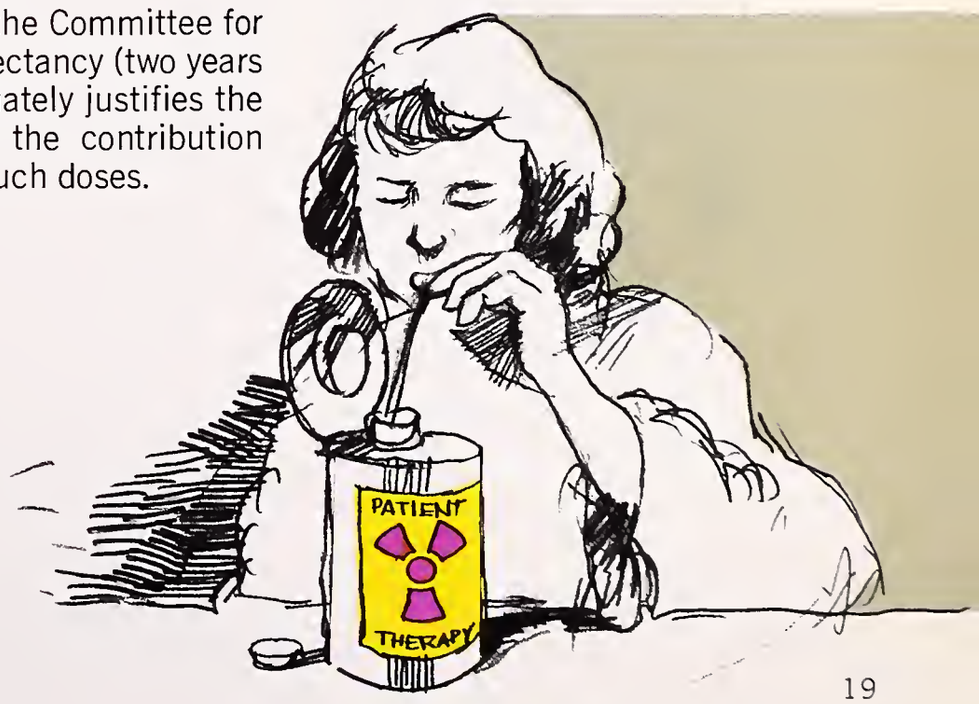
to promote progressively better techniques aimed at reducing radiation doses. All research and diagnostic procedures should be designed with these policies in mind.

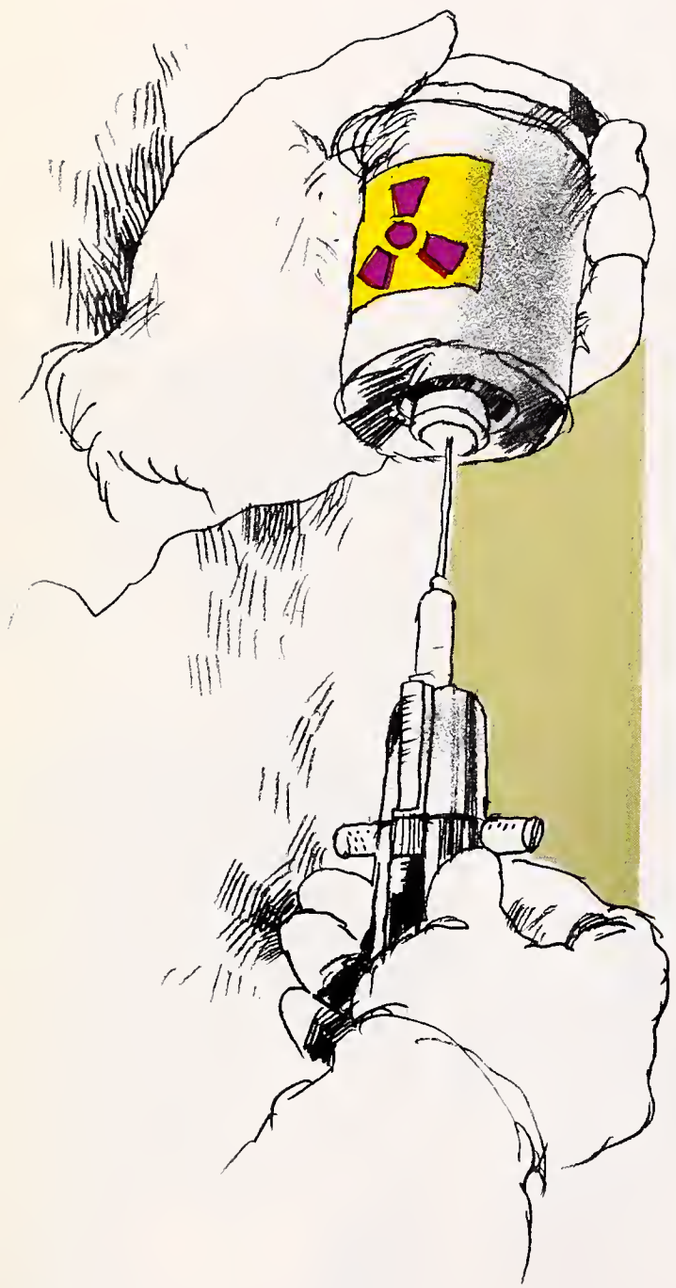
The therapeutic uses of radiation in other than malignant disease should be well justified. Applications for therapeutic uses of radiation will be reviewed by the Radiation Committee in accordance with instructions from the Director, NIH, and the Medical Board.

5. Dosage Considerations

As a general guide to the maximum permissible dose for normal volunteers and for patients, the Radiation Committee follows the recommendations of the National Council on Radiation Protection and Measurements Report No. 39, "Basic Radiation Protection Criteria" and Code of Federal Regulations, Title 21, (Food and Drugs) Part 361. Insofar as is practical, the Committee considers that the dose to normal subjects and patients should be limited to 3.0 rems to any tissue within a 13 week period or 5 rems annually, when diagnostic and experimental purposes permit. When it is necessary to exceed this dosage for the purposes of research or diagnosis because instrumentation of the required sensitivity is not available, the applicant will be required to provide justification for doses higher than these values. For all normal volunteers under the age of 18 years, and patients under the age of 18 years, and all pregnant women, this limit is reduced to 10% of the above values.

Larger doses will be considered by the Committee for use in patients with limited life expectancy (two years or less) when the application adequately justifies the procedure and the importance of the contribution which is anticipated by the use of such doses.





When considering the utilization of radioactive materials for human research and diagnosis, the investigator is urged to carefully consider the following factors:

(a) Body retention of the radioactive materials.

(b) Accumulation in critical tissues.

(c) Size of critical organ.

(d) Radiosensitivity of the tissue.

(e) Biological half-life.

(f) Effective half-life.

(g) Type and energy of the radiations.

(h) Accumulation of effects of combined or sequentially administered radioactive materials.

(i) Concomitant use of x-radiation.

6. Calibration and Nuclidic Purity Tests

Prior to administration, all radionuclides are to be calibrated and tested for nuclidic purity by the Radiopharmaceutical Section. Indicated pyrogen and sterility testing is to be arranged by the Radiopharmaceutical Section.

7. Notification of Nursing Staff

In order that the nursing staff may prepare for therapeutic radionuclide administration, the head nurse of the nursing unit which will care for the patients should be notified as far in advance as possible, preferably 24 hours or more. Those connected with the administration of the radionuclide should become familiar with nursing procedures to insure uniformity of precautions.

8. Area Designation

It is not necessary to isolate patients with routine diagnostic doses nor to post their rooms. Patients with therapeutic doses should be confined to their individual rooms, as distant from the nursing station as feasible, and the room posted with a "Radiotherapy Precautions" sign (available from the Radiation Safety staff). The Radiation Safety staff will conduct daily surveys of the patient area following therapeutic doses, removing contaminated materials such as urine, soiled bedding, etc., when necessary, and instituting controls so that the patient-care staff, adjunct personnel, and visitors are not exposed to radiation levels in excess of applicable guides. The physician in charge is responsible for requesting assistance from the Radiation Safety staff in the

event of contaminating accidents, and prior to removal of the patient from therapy precautions.

9. Record of Patient Doses

The authorization number and any dose of a radionuclide administered to a patient together with the other required data shall be recorded immediately on the patient's chart using Form PHS–412, "Radioactive Isotope Exposure Record."

10. Radioactive Waste and Disposal

Radioactive contamination of room air and sewerage should not exceed the limits approved by the NRC as stated in 10 CFR 20 (found elsewhere in this Guide). When wastes exceed these limits, they shall be disposed of with the assistance of the Radiation Safety staff.

11. Radioactive Contaminated Equipment

The authorized physician is responsible for arranging for the safe disposal of all radioactive solutions and contaminated equipment such as syringes, etc. This may be accomplished by removal to the individual's laboratory for proper decontamination or storage for decay, or by contacting the Radiation Safety staff for disposal. Under no circumstances should such solutions or equipment be left on the nursing unit, or the responsibility for disposal of these materials be delegated to the nursing staff. The Radiation Safety Officer strongly recommends the use of disposable syringes and needles for the administration of radionuclides. Disposable syringes containing only the usual residual fluid may be disposed of in the regular dry radioactive waste containers available on the nursing units. Disposable needles may also be put into the regular dry radioactive waste containers ONLY after they have been capped or after the needle point has been inserted in a small cork. This is necessary in order to preserve the integrity of the plastic bag lining the container and to protect personnel handling these liners.

12. Laboratory Specimens

There exists a danger that highly radioactive tissue specimens, blood, ascitic fluid, excreta, or cadavers may be delivered to the laboratory or pathology services, without being adequately labeled. To minimize this possibility, all specimens from such patients which are to be sent to a laboratory must be labeled "Radioactive." Preferably, the laboratory should be called in advance to give them additional

information, such as the amount of activity and special handling techniques required, if any. This includes tissue specimens, ascitic fluid, blood, urine, feces, emesis, etc.

Exemptions:

(a) When the time elapsed between the administration of the radionuclide and the time of obtaining the specimen is such as to render the specimen (in the opinion of the physician in charge of the patient or in the opinion of the Radiation Safety Officer) no longer a hazard from either a health or a contamination standpoint.

(b) When the radionuclide is administered in such a way that it remains localized and does not enter significantly into the general circulation (such as colloidal gold injected into the prostate), and the specimen is excreta or a tissue removed at a site sufficiently distant from the injection site so that it is unlikely to contain any of the radioactive material.

13. Cadavers

If a patient who has received a therapeutic dose of any radionuclide dies in the hospital within a three (3) week period after that dose, the authorized physician is requested to do the following:

(a) Tie a radioactive hazard sign to the body writing on it the specific radionuclide amount given, and the date of administration.

(b) Place the Form PHS–412 as the top sheet in the chart and write across the face of this sheet "Radioactive Body."

(c) Notify the Radiation Safety Officer. During off-duty hours the Guard Office in Building 31 should be requested to notify one of the persons on the call list maintained for such emergencies. The Radiation Safety Officer must be notified as he is responsible for giving the pathologist suitable safety instructions and for giving the required information to the funeral director.

Procedures for Nursing and Patient Care Staff

1. Diagnostic Procedures

Since there is minimal external hazard to others from routine diagnostic doses of radionuclides, there are no restrictions on the patient's activities or his contacts with other people. Nursing personnel are not required to wear personnel monitoring devices.

The following procedures apply when a patient receives radioactive material for diagnostic purposes:

(a) The Chief Nurse of the unit should request a Geiger counter and dry radioactive waste can from the Radiation Safety staff to be kept in the utility room.

(b) Patient-care personnel should use disposable gloves to handle items suspected of contamination. Particular care should be exercised in the handling of vomitus and excreta during the first 24 hours following administration of the radionuclide. Use the Geiger counter to check for contamination. Contaminated linen should be placed in a yellow laundry bag which is kept in the patient's room. Other contaminated items should be placed in the radioactive waste container. Call the Radiation Safety Office for removal of such contaminated linen and waste.

(c) Laboratory samples taken during the first days post administration should be labeled "Radioactive," as per physicians orders.

(d) Special diagnostic procedures will be evaluated on an individual basis and appropriate written instructions may be issued.

(e) Should questions arise concerning the use of radionuclides on a unit, call the Radiation Safety staff for assistance.

2. Therapy Procedures

The following procedures apply when patients receive radionuclides other than sealed sources or colloidal suspensions, in millicurie amounts for therapeutic purposes:

(a) Special Radiation Safety Procedures (Form NIH–88-7) will be issued to the Chief Nurse of the unit at the time the radionuclide is given or at the time the patient is returned from the operating room. This form will indicate precautions to be taken on a daily basis and will be reviewed each day by Radiation Safety personnel.

(b) A "Radiotherapy Precautions" sign shall be

placed at the patient's door. Radiation Safety personnel will indicate when it may be removed.

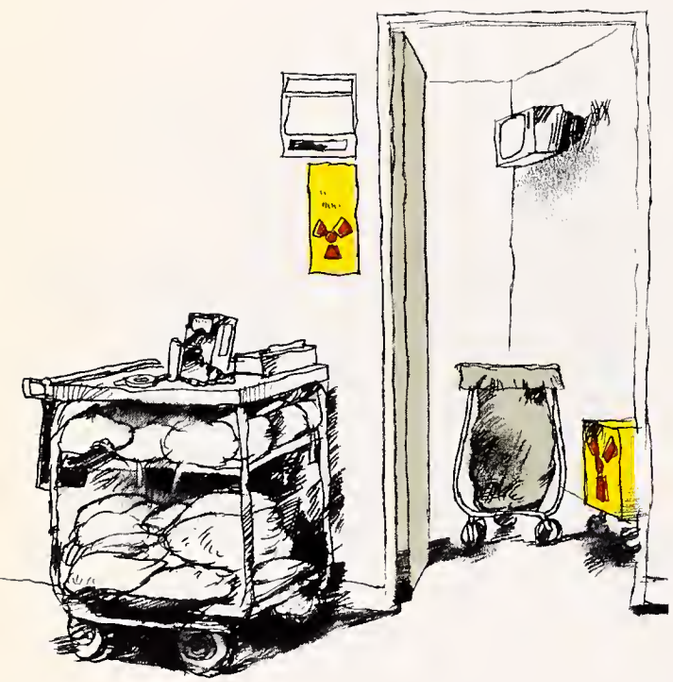
(c) The patient should be put in a room by himself. For patients receiving gamma-emitting nuclides, this room should be as distant from the nursing station as feasible. *Exception*: Patients receiving radiation source implants (radium or iridium needles) or colloidal suspensions may be placed in a room with another patient providing this second patient is receiving external beam therapy.

(d) Handling of Patient

1. When indicated on the Form NIH-88-7, the patient-care staff should wear disposable gloves while handling the patient. Used gloves should be placed in the radioactive waste can for disposal.

2. Wash hands thoroughly with soap and running water after gloves are removed.

3. After handling the patient, patient-care personnel should monitor themselves thoroughly using the Geiger counter provided for this purpose.



(e) Food Service

If feasible, paper plates and disposable utensils should be used by the patient during therapy precautions. If found contaminated after use, they should be placed in the waste container provided for this purpose.

(f) Patient's Linen

All linen, i.e., bedclothes, pajamas, towels, etc., used during the period of therapy precautions must be placed in a yellow laundry bag to be kept in the patient's room, and must not be sent to the laundry until monitored by Radiation Safety personnel.

(g) Removal of Objects and Materials From Patient's Room

All objects or materials to be removed from the therapy precautions area shall be checked for contamination. It may be necessary to remove these articles temporarily to the utility room for monitoring, due to the radiation levels in the vicinity of the patient.

(h) Disposal of Radioactive Excreta

1. Feces should be passed in the toilet whenever possible. If a bedpan is used, it must be handled with disposable gloves. The same bedpan should be used until treatment is completed and its use restricted to that particular patient.

2. Urine shall be saved in stoppered bottles and if the radionuclide is a gamma-emitter, the bottles shall be kept in a shielded storage container provided by the Radiation Safety staff. Urine container, urinals, specimen bottles, etc., should be handled only by the patient if at all possible.

(i) Housekeeping Personnel

Housekeeping personnel shall not enter the room unless indicated on the Form NIH-88-7.

(j) Accidents

In case of an accident which might produce a radiation hazard (e.g., the spillage of contaminated urine on the floor),

CALL AT ONCE:

During Regular Working Hours
The Physician in Charge,
Radiation Safety Officer,
and
Chief of Nursing Service.
Outside of Regular Working Hours:
Nursing Supervisor in Charge,
Physician in Charge,
and
Guard Office in Building 31 for names of Radiation Safety Office personnel on call.

3. Colloidal Suspensions and Sealed Sources

The following apply when patients receive therapy utilizing colloidal suspensions or sealed sources, such as needles, tubes and plaques containing iridium-192, cobalt-60, radium, radon, etc.:

(a) All dressings, bedclothes, sanitary napkins, bedpans, etc., or any material removed from the vicinity of the treatment site shall be carefully monitored to assure that the source has not been removed or displaced.

(b) The above-mentioned items (a), (b), (c), and (i) of Part 2 shall also apply.

(c) Items (d), (e), (f), (g), and (h) do not apply to these cases since there is little if any chance of contamination.

(d) The nursing staff should be alert to any sealed sources which may have moved from their original positions. Should an implanted source become separated from the patient, proceed as in 2-(j) above.

Radiation Producing Equipment Operator's Responsibility

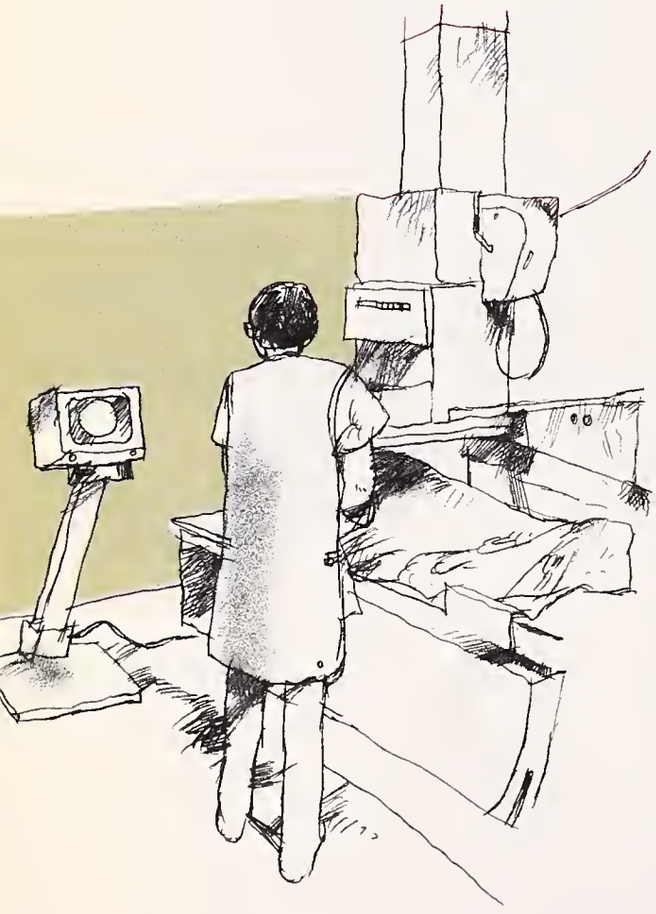
The operator of any radiation producing equipment is responsible for:

1. Notifying the Radiation Safety Office when there is any change in the setup, i.e., new equipment installed, changes in shielding, change in output of radiation, or change in usage of the unit.

2. Requesting and wearing appropriate monitoring devices. Always wear the assigned monitoring device (e.g., film badge) when working with the unit. Whenever protective lead aprons are worn, the body monitor should be worn on the outside of the apron at the neckline. In addition, wrist monitors are to be worn if the unprotected hands and forearms must come in close proximity to the beam.

3. Keeping exposure as low as possible. The operator must never expose himself to the direct beam, and must not stand within one meter of the tube or irradiated target while the unit is in operation unless adequately shielded. Make full use of protective barriers, lead aprons, gloves, and goggles.

4. Clearing the area of all nonessential personnel. The operator should insist that all nonessential personnel leave the exposure area before operating the unit, and that all essential personnel be adequately shielded.



5. Observing any restrictions on the use of the unit recommended by the Radiation Safety staff.

6. Adequate dark adaptation. The eyes of the fluoroscopist should be well dark-adapted before he uses a fluoroscope without image intensifying equipment. It is inexcusable to increase the output of the unit to compensate for poor dark adaptation.

7. Using minimum exposure factors. Fluoroscopic work shall be performed in the minimum time possible using the lowest dose rate and smallest aperture consistent with clinical requirements.

8. Visually monitoring tube current and potential of fluoroscopic equipment with image intensifiers at frequent intervals, because under automatic brightness control these variables can rise to high values.

9. Recording data of fluoroscopic and cineradiographic studies on patients on Form NIH–378, "Radiation Exposure Record," and maintaining this form in the patient's record.

10. Notifying the supervisor and the Radiation Safety Officer immediately of any accidental exposures to radiation.

11. Keeping the unit disconnected or locked when not in actual use.

Policies for Radiation Producing Machines and Areas

1. All operating personnel and personnel in the immediate area will be required to wear a film badge or other personnel monitoring device.

2. Areas in which radiation producing machines are located or are being used shall be posted with the characteristic "CAUTION RADIATION" sign. In addition, the controls shall bear a decal with the statement: "CAUTION RADIATION—This equipment produces radiation when energized." Labels and decals are available from the Radiation Safety Office.

Exception: Diagnostic and patient treatment areas need not be so marked, provided that a person is charged with the responsibility for protection of employees, patients, and authorized visitors against radiation injuries, and for the execution of Radiation Safety recommendations.

3. The structural shielding requirements of any new installation, or an existing one in which changes are contemplated, shall be discussed with the Radiation Safety staff.

4. An annual, scheduled survey of all radiation producing equipment used on patients shall be made by Radiation Safety personnel. In addition, radiation surveys will be made of all new installations and all existing installations after every change that might increase the radiation hazard (e.g., replacement of x-ray tube, changes in filtration of beam).

5. Unless measurements indicate that they are not needed, protective aprons shall be worn by the physician, nurse, technician, and all other persons within the room or area who are frequently or habitually exposed to radiation.

6. Dose rates for the beam shall be determined for all units used on human subjects and will be reported to the operator in milliroentgens per milliampere-second or milliroentgens per minute. The "Radiation Exposure Record," Form NIH–378, shall be completed for fluoroscopic and cineradiographic studies and maintained in the patient's record.

7. In the operation of mobile and dental units:

(a) The operator should stand as far as possible from the tube and patient during exposure, and should wear a protective apron, or step behind an adequate shield.

(b) An operator, standing at least 6 feet from the tube and patient, should not make more than 5,000 milliampere-seconds of exposure during any one week. Rotation of operators or the use of portable shields is recommended for greater workloads.

8. The hand of the fluoroscopist should never be placed in the useful beam unless the beam is attenuated by the patient and a protective glove of at least 0.25 mm lead equivalent is worn.

9. No person shall be regularly employed to hold patients during exposure, nor shall anyone from the Diagnostic Radiology Department ever be permitted to perform such service. The person holding the patient shall wear protective gloves and a protective apron. No part of this person's body should be in the unattenuated useful beam.

10. If safe use of the installation depends upon mechanical restriction of the orientation of the radiation beam, or upon limitations (voltage, current, time, permanent filter, and maximum aperture) in the output of the unit, then these restrictions shall be rigidly followed.

11. Shutter mechanisms and interlocking devices should not be tampered with and shall be inspected at frequent intervals to insure proper operation.

12. All protective devices that may become defective due to use or abuse, such as protective lead aprons or gloves, should be inspected for radiation leakage at least every six months, or whenever the integrity of the equipment is suspect.

13. A manually reset cumulative timing device shall be used which will either indicate elapsed time or turn off the apparatus when the total exposure reaches a certain previously determined limit.

14. In cineradiography, tube currents and potentials are often higher than those used in fluoroscopy. Thus, special care should be taken to limit patient exposure. The exposure rates on these cineradiography units shall be determined during the annual survey.

15. X-ray diffraction equipment can be particularly hazardous because of high exposure rates in the primary beam (e.g., in excess of 500,000 roentgens per minute at the x-ray tube port).

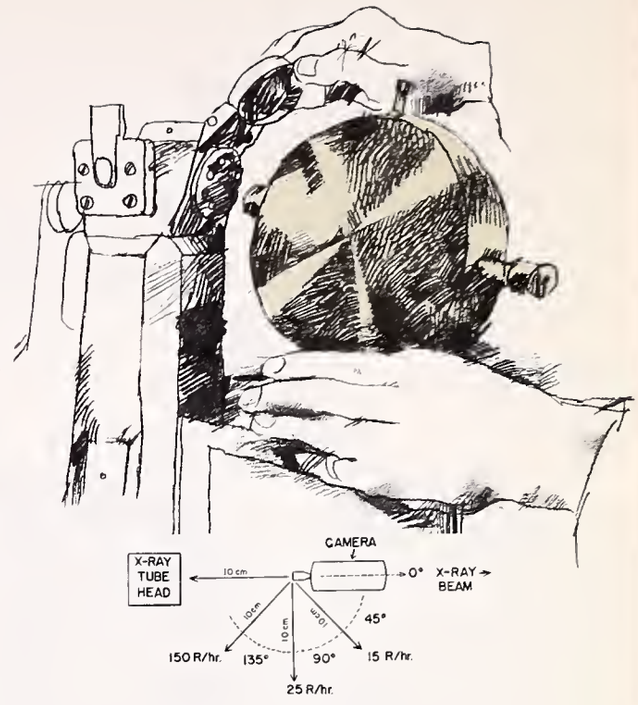
(a) A radiation survey shall be made by the Radiation Safety staff before a new installation is placed in routine operation and whenever changes are made which could adversely affect radiation protection. The equipment shall be frequently inspected for radiation leakage and a radiation survey shall be made at least annually by Radiation Safety personnel.

(b) Appropriate operating procedures and safety measures approved by the Radiation Committee shall be established and followed for these units.

16. Personnel specifically responsible for such equipment shall insure that all workers in the area are monitored in accordance with the requirements for the specific unit.

17. For larger, individually licensed irradiators and accelerators, specific operating and emergency procedures shall be established and posted. All users of this equipment shall operate it in compliance with these posted instructions.

18. All interlocks, visual and audible warning devices, and monitoring equipment shall be inspected for proper operation at six month intervals by Radiation Safety personnel.



Procurement of Radiation Sources

The following procedures for the procurement of radiation sources are intended to insure compliance with the terms and conditions of the license issued by NRC, and the regulations imposed by the Director, NIH:

1. The Radiation Safety Officer must be notified in advance of the procurement of all radiation sources whether ionizing radiation producing machines, NRC-licensable or accelerator-produced radionuclide, radium, or other radioactive materials.

2. When the use of radiation sources is planned, the investigator must indicate to the Radiation Com-

mittee his training and experience in this area. This is done by submitting one copy of the Form NIH-88-2 "Application for Use of Radioisotopes at the National Institutes of Health" to the Radiation Safety Office. When the investigator makes application to the Committee, it is understood that *he accepts the responsibility for complying with the regulations governing the safe use of sources in NIH controlled areas.*

3. Upon notification of approval of his qualifications, the investigator then submits Form NIH–88–1, "Request for Purchase and Use of Radionuclides," to the Radiation Safety Office. The form covers only the quantities specified on a single requisition. The form must be completed regardless of the method of acquisition. In cases other than purchase, the form serves as the required notice to the Radiation Safety Office that the receipt of radioactive materials is contemplated through gifts or transfers from any source.

4. Established users of the NIH license may procure radionuclides under the Telephone Charge Order (TCO) system, provided all conditions of the Small Purchase Procedures Manual (NIH Manual Handbook 2600–103–26.9) are met. Authorized investigators are reminded that: the dollar limit for radionuclides is $500 and for radionuclides being used under the NIH Broad License delivery must be made within ten (10) days to: *Radiation Safety Officer, National Institutes of Health, Building 21, Radionuclide Laboratory, Bethesda, Maryland 20014.* See Small Purchase Procedures Manual for step-by-step instructions for obtaining radionuclides by TCO and for list of TCO Account Suppliers.

5. Purchase orders exceeding $500 will be requisitioned in the usual manner by using Form PHS–402–1, "Requisition for Equipment and Supplies," which shall be clearly labeled *"Radionuclide Order."* The requisition must be completed in all normal respects and, in addition, specify that delivery be made to the *Radiation Safety Officer, National Institutes of Health, Building 21, Radionuclide Laboratory, Bethesda, Maryland 20014.* The requisition and accompanying Form NIH-88-1 are routed through Radiation Safety, Bldg. 21, to the Procurement Section, Bldg. 13.

6. The purchase order will then be prepared by the Procurement Section, Material Management, and routed through the Radiation Safety Office for final approval. The Radiation Safety Officer will indicate approval and place the NRC license number on the purchase order and forward it to the supplier.

7. The Radiation Safety Office will be the receiving point on the NIH reservation for such material and will make the actual delivery to the ordering investigator. Any changes in the original shipping instructions should be furnished to this office by the investigator or the Institute ordering office serving him. Shipping information received from the supplier by the Procurement Section and the Receiving Control Reports Section, Bldg. 13, will be furnished immediately to the Radiation Safety Office which in turn will keep the ordering investigator properly informed.

8. In the case of ionizing radiation producing machines such as x-ray units, linear accelerators, etc., the notification is made on Form NIH–88-13, "Request for Authorization to Purchase and Use Radiation Producing Machinery or Equipment." The filing of Training and Experience Form NIH-88-2 may or may not be required by the Radiation Committee depending on the device(s), its complexity and the proposed uses. Consult with the Radiation Safety Officer concerning this Training and Experience requirement. The equipment is then requisitioned in the usual manner using Form PHS–402–1.

Shipping Radioactive Materials

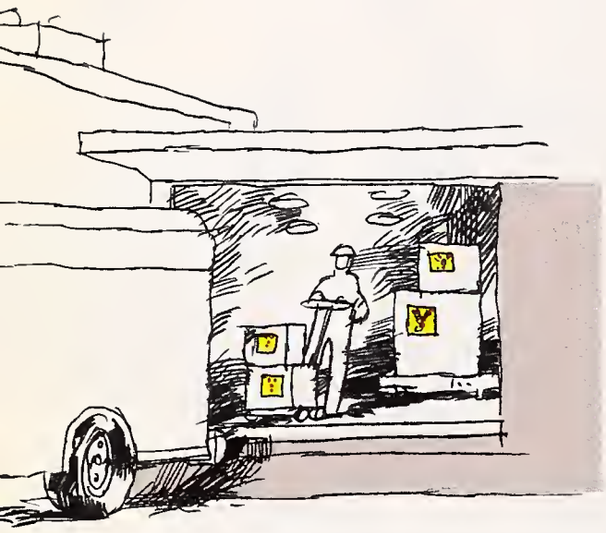
1. When radioactive material is to be shipped from NIH, the shipper must notify the Radiation Safety Office instead of the Shipping and Receiving Section. The Radiation Safety staff will pick up these shipments on telephone request. The usual NIH shipping request Form NIH 1884 is to be prepared and will accompany the container. Under item 7 of this form the description of articles must include radionuclide, chemical form, and activity (in μCi or mCi).

2. The recipient of any material to be shipped from NIH must provide evidence of an NRC (or agreement state*) license by furnishing a copy of his license to the Radiation Safety Office before shipment can be made. Noncompliance with this requirement is a violation of the Atomic Energy Act and is subject to criminal prosecution as well as denial to NIH of further NRC-controlled radionuclides. Check first with the Radiation Safety staff by phone to see if the recipient's license is already on file. If not, then request a copy from the recipient in order to fulfill this requirement.

*Agreement States: Those states that have entered into agreements with the NRC for the control of radioactive material.

3. The investigator is reminded that the NIH specific license of broad scope *covers only the Bethesda reservation, Auburn Building and the Danac Buildings (4 and 5) in Rockville*. Materials transported by the investigator to other installations must be transferred to the respective licensees in that area as in paragraph 2 above and in a manner complying with applicable NRC and/or Department of Transportation regulations.

4. When an empty radionuclide container is to be returned to the supplier, the ordering investigator must notify the Radiation Safety Office, who will certify that it is free of contamination. The container may then be returned through normal channels. Promptness in returning the container is urged. Conditions of purchase usually require that such containers will be returned within a specified period of time.



Off-Site Use of Radionuclides by NIH Staff

As specified in NIH Manual Issuance 1344, NIH investigators working with radioactive materials and radiation producing devices will comply with the following:

1. All off-site† uses of radionuclides, domestic or foreign, under "generally licensed quantities" (10 CFR 31.100) or individual NRC or agreement state license should be subject to the same scientific review and approval by the Radiation Committee as prevails for in-house use.

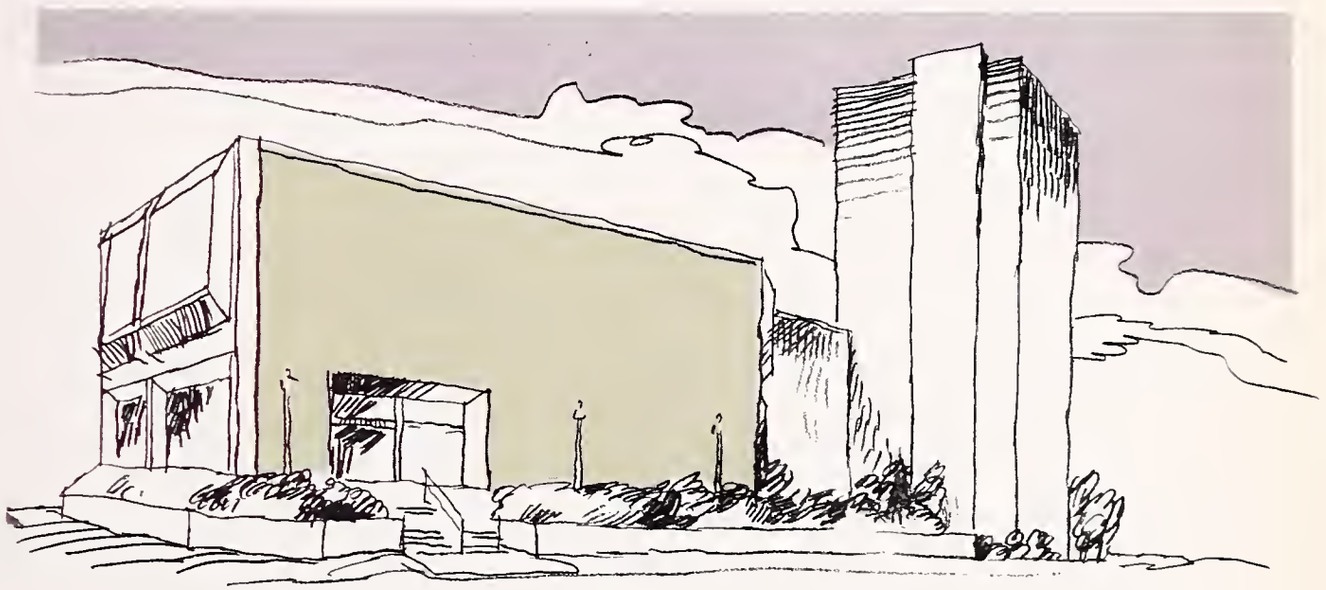
2. Off-site domestic use under various forms of NRC or agreement state license of an NIH scientist may be permitted. This requires approval of the same type of application as is required for NIH use, plus approval of the application form as submitted to NRC or the agreement state, including specific data with respect to proposed methods of compliance with 10 CFR, Parts 19 and 20 or similar agreement state

†Off-site: All research locations other than the NIH reservation, the Auburn Building (Bethesda) and Danac Buildings 4 and 5 (Rockville) where NIH personnel are assigned.

regulations. The NIH Radiation Safety Office will provide assistance with these applications and requires copies of all relevant correspondence, of the final licenses, of renewals, and of subsequent amendments to the licenses.

3. Off-site foreign use may be authorized following compliance with paragraph (1) and receipt by the Radiation Committee of an acceptable statement indicating the full knowledge and agreement of an appropriate authority in the host country.

4. All NIH scientists using radionuclides under any circumstances in off-site locations, domestic or foreign, must use NIH personnel monitoring devices when indicated or be under an equivalent monitoring program acceptable to and reporting to the NIH Radiation Safety Office.



5. The NIH Radiation Committee and Radiation Safety Office are authorized to intervene and apply the applicable NIH regulations to off-site uses of other sources of ionizing radiations employed by NIH personnel.

6. Users of radionuclides authorized and procured under the NIH Broad NRC License are reminded that this license is specific for the NIH *Bethesda reservation, Auburn Building, Danac Buildings 4 and 5, and other buildings specifically mentioned in amendments to the NIH Broad License*. This means that the transfer of radionuclides from these locations to off-site premises requires clearance through the NIH Radiation Safety Office. Transfers of radionuclides from off-site locations to NIH must be made in accordance with the requirements of "Procurement of Radiation Sources."

Appendix

Glossary

ABSORBED DOSE: The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. (See Rad)

ABSORPTION: The phenomenon by which radiation imparts some or all of its energy to any material through which it passes.

ACTIVITY: The number of nuclear disintegrations occurring in a given quantity of material per unit time. (See Curie)

ALPHA PARTICLE: A strongly ionizing particle emitted from the nucleus during radioactive decay having a mass and charge equal in magnitude to a helium nucleus, consisting of 2 protons and 2 neutrons with a double positive charge.

ALPHA RAY: A stream of fast-moving helium nuclei (alpha particles), a strongly ionizing and weakly penetrating radiation.

ANNIHILATION (Electron): An interaction between a positive and negative electron; their energy, including rest energy, being converted into electromagnetic radiation (annihilation radiation).

ATOM: Smallest particle of an element which is capable of entering into a chemical reaction.

AUTORADIOGRAPH: Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

BACKGROUND RADIATION: Ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

BETA PARTICLE: Charged particle emitted from the nucleus of an atom, having a mass and charge equal in magnitude to that of the electron.

BETA RAY: A stream of high speed electrons or positrons of nuclear origin more penetrating but less ionizing than alpha rays.

BREMSSTRAHLUNG: Electromagnetic (x-ray) radiation associated with the deceleration of charged particles passing through matter. Usually associated with energetic beta emitters, e.g., phosphorus-32.

CALIBRATION: Determination of variation from standard, or accuracy, of a measuring instrument to ascertain necessary correction factors.

CONTAMINATION, RADIOACTIVE: Deposition of

radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. The harm may be vitiating the validity of an experiment or a procedure, or in actually being a source of excessive exposure to personnel.

CARRIER FREE: An adjective applied to one or more radionuclides of an element in minute quantity, essentially undiluted with stable isotope carrier.

COUNT (Radiation Measurements): The external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term is often erroneously used to designate a disintegration, ionizing event, or voltage pulse.

CRITICAL ORGAN: That organ or tissue, the irradiation of which will result in the greatest hazard to the health of the individual or his descendants.

CURIE: The quantity of any radioactive material in which the number of disintegrations is 3.700×10^{10} per second. Abbrevated Ci.

Millicurie: One-thousandth of a curie (3.7×10^{7} disintegrations per second). Abbreviated mCi. Microcurie: One millionth of a curie (3.7×10^{4} disintegrations per second). Abbreviated μCi. Picocurie: One millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute). Abbreviated pCi.

DECAY, RADIOACTIVE: Disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

DOSE: A general term denoting the quantity of radiation or energy absorbed in a specified mass. For special purposes it must be appropriately qualified, e.g., absorbed dose.

DOSE, ABSORBED: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad, which is 100 ergs/gram.

DOSE EQUIVALENT: A quantity used in radiation protection expressing all radiation on a common scale for calculating the effective absorbed dose. The unit of dose equivalent is the rem, which is numerically equal to the absorbed dose in rads multiplied by certain modifying factors such as the quality factor, the distribution factor, etc.

EFFICIENCY (Counters): A measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably so it is well to make sure which factors (window, transmission, sensitive volume, energy dependence, etc.) are included in a given case.

ELECTRON: Negatively charged elementary particle which is a constituent of every neutral atom. Its unit of negative electricity equals 4.8×10^{-19} coulombs. Its mass is 0.00549 atomic mass units.

ELECTRON CAPTURE: A mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from the particular electron shell is designated as "K-electron capture," "L-electron capture," etc.

ELECTRON VOLT: A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbreviated eV. Larger multiple units of the electron volt frequently used are: keV for thousand or kiloelectron volts, MeV for million electron volts and BeV for billion electron volts.

EXPOSURE: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the roentgen.

FILM BADGE: A packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.

FILTER (Radiology), PRIMARY: A sheet of material, usually metal, placed in a beam of radiation to remove, as far as possible, the less penetrating components of the beam. **SECONDARY**: A sheet of material of lower atomic number, relative to that of the primary filter, placed in the filtered beam of radiation to remove characteristic radiation produced by the primary filter.

GAMMA RAY: Very penerating electromagnetic radiation of nuclear origin. Except for origin, identical to x-ray.

GEIGER-MUELLER (G-M) COUNTER: Highly sensitive gas-filled detector and associated circuitry used for radiation detection and measurement.

GENETIC EFFECT OF RADIATION: Inheritable changes, chiefly mutations, produced by the absorption of ionizing radiations. On the basis of present knowledge these effects are purely additive, and there is no recovery.

HALF-LIFE, BIOLOGICAL: The time required for the body to eliminate one-half of an administered dose of any substance by the regular processes of elimination. This time is approximately the same

for both stable and radionuclides of a particular element.

HALF-LIFE, EFFECTIVE: Time required for a radioactive nuclide in a system to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life} \times \text{Radioactive half-life}}{\text{Biological half-life} + \text{Radioactive half-life}}$$

HALF-LIFE, RADIOACTIVE: Time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

HALF VALUE LAYER (Half thickness): The thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

HEALTH PHYSICS: A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

INVERSE SQUARE LAW: The intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example: If the radiation exposure is 100 R/hr at 1 inch from a source, the exposure will be 0.01 R/hr at 100 inches.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

IONIZATION: The process by which a neutral atom or molecule acquires either a positive or a negative charge.

IONIZATION CHAMBER: An instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

IONIZATION, SPECIFIC: The number of ion pairs per unit length of path of ionizing radiation in a medium; e.g., per centimeter of air or per micron of tissue.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

ISOTOPES: Nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

LABELED COMPOUND: A compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition this compound or its fragments may be followed through physical, chemical or biological processes.

MAXIMUM PERMISSIBLE DOSE (MPD): Maximum dose of radiation which may be received by persons working with ionizing radiation, which will produce no detectable damage over the normal life span.

MILLIROENTGEN (mR): A submultiple of the roentgen equal to one one-thousandth (1/1000th) of a roentgen. (See Roentgen)

MONITORING, RADIOLOGICAL: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region as a safety measure for purposes of health protection.

Area Monitoring: Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room or equipment.

Personnel Monitoring: Monitoring any part of an individual, his breath, excretions, or any part of his clothing. (See Radiological Survey)

NEUTRON: Elementary particle with a mass approximately the same as that of a hydrogen atom and electrically neutral. It has a half-life in minutes and decays in a free state into a proton and an electron.

NUCLIDE: A species of atom characterized by its mass number, atomic number, and energy state of its nucleus, provided that the atom is capable of existing for a measurable time.

PROTECTIVE BARRIERS: Barriers of radiation absorbing material, such as lead, concrete, plaster, and plastic, that are used to reduce radiation exposure.

Protective Barriers, Primary: Barriers sufficient to attenuate the useful beam to the required degree.

Protective Barriers, Secondary: Barriers sufficient to attenuate stray or scattered radiation to the required degree.

RADIATION: 1. The emission and propagation of energy through space or through a material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves. 2. The energy propagated through a material medium as waves; for example, energy in the form of electromagnetic waves or of elastic waves. The term "radiation" or "radiant energy," when unqualified, usually refers to electromagnetic radiation. Such radiation commonly is classified according to frequency as Hertzian, infrared, visible (light), ultraviolet, x-ray, and gamma ray. 3. By extension,

corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type, as cosmic radiation.

RADIOLOGICAL SURVEY: Evaluation of the radiation hazards incident to the production, use or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

RADIONUCLIDE: A nuclide with an unstable ratio of neutrons to protons placing the nucleus in a state of stress. In an attempt to reorganize to a more stable state, it may undergo various types of rearrangement that involve the release of radiation.

RADIOTOXICITY: Term referring to the potential of an isotope to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE): For a particular living organism or part of an organism, the ratio of the absorbed dose of a reference radiation that produces a specified biological effect to the absorbed dose of the radiation of interest that produces the same biological effect.

REM: The special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors.

ROENTGEN (R): The quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 grams of dry air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. The roentgen is the special unit of exposure.

SCINTILLATION COUNTER: A counter in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

SHIELDING MATERIAL: Any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water, and plastic are examples of commonly used shielding material.

SMEAR (Smear or Swipe Test): A procedure in which a swab, e.g., a circle of filter paper, is rubbed on a surface and its radioactivity measured to determine if the surface is contaminated with loose radioactive material.

SPECIFIC ACTIVITY: Total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.

TRACER, ISOTOPIC: The isotope or nonnatural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.

THERMOLUMINESCENT DOSIMETER: A dosimeter made of certain crystalline material which is capable of both storing a fraction of absorbed ionizing radiation and releasing this energy in the form of visible photons when heated. The amount of light released can be used as a measure of radiation exposure to these crystals.

X-RAYS: Penetrating electromagnetic radiations having wave lengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x-rays. These rays are sometimes called roentgen rays after their discoverer, W. C. Roentgen.

GUIDELINES FOR MAXIMUM PERMISSIBLE DOSES FOR NIH PERSONNEL

Organ	Dose in mrem			
	Year	Quarter	Month	Week
Whole Body (Including Gonads, Lens of Eye, Red Bone Marrow)	5,000	1,250	400	100
Forearms, Hands, Feet and Ankles	75,000	18,750	6,250	1,500
Skin of Whole Body	30,000	7,500	2,500	650
Fertile Age Women*	3,000		250	60
Pregnant Women or Employees Under 18 Years of Age	500	125	40	10

For information on specific organs or tissues not listed, consult with Radiation Committee or Radiation Safety Officer.

* The National Council on Radiation Protection and Measurements, in Report No. 39, recommends a maximum permissible dose of 2 to 3 rem per year, at an even rate. Also see U.S. Nuclear Regulatory Commission Guide 8.13 in the Appendix.

CLASSIFICATION OF RADIONUCLIDES ACCORDING TO RELATIVE RADIOACTIVITY PER UNIT ACTIVITY

(Based on Published Data and NIH User Experience)

Class 1 (very high toxicity)
Sr-90 + Y-90, *Pb-210 + Bi-210(Ra D + E), Po-210, At-211, *Ra-226 + 55% *daughter products, Ac-227, *U-233, Pu-239, *Am-241, Cm-242, plus other transuranium isotopes.

Class 2 (high toxicity)
Ca-45, *Ca-47, *Fe-59, *Sr-85, Sr-89, Y-91, *Ru-106 + Rh-106, *I-125, *I-131, *Ba-140 + *La-140, Ce-144 + *Pr-144, Sm-151, *Eu-154, *Tm-170, *Hg-203, *Th-234 + *Pa-234, *natural uranium.

Class 3 (moderate toxicity)
*Na-22, *Na-24, P-32, P-33, S-35, Cl-36, *K-42, *Sc-46, *Sc-47, *Sc-48, *V-48, *Mn-52, *Mn-54, *Mn-56, Fe-55, *Co-57, *Co-58, *Co-60, Ni-59, *Cu-64, *Cu-67, *Zn-65, *Ga-67, *Ga-72, *As-74, *As-76, *Br-82, *Kr-85, *Rb-84, *Rb-86, *Zr-95 + *Nb-95, *Nb-95, *Mo-99, Tc-98, *Rh-105, Pd-103 + Rh-103, *Ag-105, *Ag-111, Cd-109 + *Ag-109, *Sn-113, *Te-127, *Te-129, *I-132, *Xe-133, *Cs-137 + *Ba-137, *La-140, Pr-143, Pm-147, *Ho-166, *Lu-177, *Ta-182, *W-181, *Re-183, Ir-190, *Ir-192, Pt-191, *Pt-193, *Au-196, *Au-198, *Au-199, Tl-200, Tl-202, Tl-204, *Pb-203, *Hg-197.

Class 4 (slight toxicity)
H-3, Be-7, C-14, *F-18, *Cr-51, Ge-71, *Sr-87m, *Tc-99m, *Tl-201.

*Gamma emitter and/or associated photon emitter.

GUIDELINES FOR MAXIMUM ACTIVITIES IN NIH LABORATORIES

Radiotoxicity of Radionuclides	Minimum Significant Quantity Utilized	Typical NIH Laboratory	Radionuclide Laboratory Building 21 (1)
Very high	0.1 μCi	10 μCi or less	10 μCi–10 mCi
High	1.0 μCi	100 μCi or less	100 μCi–100 mCi
Moderate	10 μCi	1 mCi or less	1 mCi–1 Ci
Slight	100 μCi	10 mci or less	10 mCi–10 Ci

Modifying factors should be applied to the quantities indicated in the last 2 columns of the above table, according to the complexity of the procedures to be followed. The following factors are suggested but due regard should be paid to the circumstances affecting individual cases.

Procedure	*Modifying factor*
Storage (stock solutions)	× 100
Very simple wet operations	× 10
Normal chemical operations	× 1
Complex wet operations with risk of spills	× 0.1
Simple dry operations	× 0.1
Dry and dusty operations	× 0.01

(1) With proper documentation of experimental protocol and with approval of the Radiation Committee, investigators may be permitted to use these quantities in NIH laboratories outside Building 21. With similar documentation, activities exceeding these maximum quantities may be approved for use in Building 21 only.

SELECTED PROPERTIES OF MOST FREQUENTLY ORDERED RADIONUCLIDES

Nuclide	Maximum Beta Energy (MeV)	Gamma Energy (MeV)	Iγ mR/hr/mCi at 1 m	Critical organ	MPB (μCi)	Half-Life	
						Radioactive	Biological (days)
^{3}H	0.0186			Body Tissue	2000	12.26y	12
^{14}C	0.156			Body Fat	180	5730y	12
^{24}Na	1.389	1.369 (100%) 2.754 (100%)	1.84	Total Body	7	14.96h	11
^{32}P	1.710			Bone	3	14.28d	1155
^{33}P	0.248			Bone	32	24.4d	1155
^{35}S	0.167			Testis Total Body	0.18 400	87.9d	623
^{51}Cr		0.32(9%)	0.016	Total Body	1100	27.8d	616
^{125}I		28 keV average (143%)	0.07	Thyroid	0.57	60.2d	138
^{131}I	0.606	0.637 (6.8%) 0.364 (82%)	0.22	Thyroid	0.078	8.05d	138

Column (4), 1γ Milliroentgens per hour at 1 meter from 1 millicurie.

Column (5), Critical organ. The organ that receives the limiting dose equivalent from a substained burden (see discussion of Column 6). These organs are chosen based on the way in which the radioactive material is distributed within the body after intake.

Column (6), Maximum Permissible Burden (MPB). The amount of a radionuclide in an organ which, when sustained in that organ continuously, would produce the maximum permissible dose equivalent. The corresponding maximum permissible dose equivalents for the organs above are: body fat and thyroid, 15 rem/yr; and all others 5 rem/yr.

Column (7), Radioactive Half-Life. Present best value, obtained from "Table of Isotopes—6th Edition" by C. M. Lederer, J. M. Hollander, and I. Perlman, John Wiley & Sons, New York, 1967. The abbreviations used here are: s, second; m, minute; h, hour; d, day; and y, year.

Column (8), Biological Half-Life. The time required for one-half of the stable element to be removed from the critical organ by biological processes, as listed by the ICRP. The actual half-life of elimination depends also on the half-life of the isotope. The "effective half-life" in the critical organ (T_{eff}) is given by $T_{eff} = \frac{T_r T_b}{T_r + T_b}$ where T_r is the radioactive half-life and T_b is the biological half-life.

Rules of Thumb

Beta Particles

a. Beta particles of at least 70 keV energy are required to penetrate the nominal protective layer of the skin (7 mg/cm^2 or 0.07 mm).

b. The average energy of a beta-ray spectrum is approximately one-third the maximum energy.

c. The range of beta particles in air is ~ 12 ft/MeV. (Maximum range of ^{32}P beta is 1.71 MeV $\times$ 12 ft/Mev $\cong$ 20 ft).

d. The dose rate in rads per hour in a solution by a beta emitter is 1.12 EC/ρ, where E is the average beta energy per disintegration in MeV, C is the concentration in microcuries per cubic centimeter, and ρ is the density of the medium in grams per cubic centimeter. The dose rate at the surface of the solution is one-half the value given by this relation. (For ^{32}P average energy of approximately 0.7 MeV, the dose rate from 1 μCi/cm^3 (in water) is 1.48 rads/hr).

e. The surface dose rate through the nominal protective layer of skin (7 mg/cm^2) from a uniform thin deposition of 1 μCi/cm^2 is about 9 rads/hour for energies above about 0.6 MeV. Note that in a thin layer, the beta dose rate exceeds the gamma dose rate, for equal energies released, by about a factor of 100.

f. For a point source of beta radiation (neglecting self and air absorption) of strength mCi millicuries, the dose rate at 1 cm is approximately equal to 200 $\times$ mCi rads/hour and varies only slowly with beta energy. Dose rate for 1 mCi ^{32}P at 1 cm is approximately 200 rads/hour.

Gamma Rays

a. For a point source gamma emitter with energies between 0.07 and 4 MeV, the exposure rate (mR/hr) within $\pm$ 20% at 1 foot is 6 $\times$ mCi $\times$ E $\times$ n, where mCi is the number of millicuries; E, the energy in MeV; and n, the number of gammas per disintegration.

b. The dose rate to tissue in rads per hour in an infinite medium uniformly contaminated by a gamma emitter is 2.12 EC/ρ, where C is the number of microcuries per cubic centimeter, E is the average gamma energy per

disintegration in MeV, and ρ is the density of the medium. At the surface of a large body, the dose rate is about half of this.

X-Ray

a. The exposure rate at 2 feet from diagnostic x-ray equipment operated at 100 kVp and 100 milliamperes is approximately 2.3 roentgens/second.

b. Exposure rate at the fluoroscopy table with tube potential at 80 kVp and tube current of 1 milliampere should not exceed 2.1 roentgens/minute.

c. Scattered radiation can be as penetrating as the primary beam.

X-Ray Diffraction

a. The x-ray beam intensities from the primary beam can be as much as 400,000 R/min.

b. Scattered radiation 10 cm from the points of scatter about the x-ray tube head has been measured in the order of 150 R/hr.

c. The threshold dose sufficient to produce skin erythema is 300 to 400 roentgens.

d. The minimum cataractogenic single dose is 200 rads, while a dose of 750 rads exhibits a high incidence of cataract formation.

Miscellaneous

a. The activity of any radionuclide is reduced to less than 1% after 7 half-lives (i.e., $2^{-7} = 0.8\%$).

b. For material with a half-life greater than six days, the change in activity in 24 hours will be less than 10%.

MIRD Absorbed Dose Calculations

The following are examples of the equations and calculations necessary to estimate absorbed dose according to the schema developed and published by the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine. Pamphlets containing the required data may be obtained by writing: MIRD Committee, 404 Church Ave., Suite 15, Maryville, Tenn. 37801. A limited number of copies are available for short term loan from the Radiation Safety office. Reminder: when using the MIRD method, it is most important to keep all quantities in the specified units.

A. General Equation

$$\bar{D}(r_k \leftarrow r_h) = \tilde{A}\, S(r_k \leftarrow r_h)$$

where $\bar{D}(r_k \leftarrow r_h)$ = mean absorbed dose (in rads) to target organ r_k from source organ r_h,
$\tilde{A}$ = cumulated activity in source organ r_h, and
$S(r_k \leftarrow r_h)$ = the "S-factor", or absorbed dose per unit cumulated activity (in rad/μCi-hr) for target organ r_k, and source organ r_h. S is tabulated by nuclide for a large number of source-organ target-organ configurations in MIRD pamphlet No. 11 (1).

B. Other Important Equations

1. $$\tilde{A} = A_o \int_{t_1}^{t_2} \exp(-0.693t/T_{eff})\, dt$$

where A_o = initial activity in source volume (μCi)
t_1 = initial time during which dose is to be calculated (hours after initial uptake).
t_2 = final time during which dose is to be calculated (hours after initial intake).
T_{eff} = effective half-life (h)

2. $$\frac{1}{T_{eff}} = \frac{1}{T_{bio}} + \frac{1}{T_{phy}}$$

where T_{bio} = biological half-life (h) of radionuclide in the source volume
T_{phy} = physical half-life (h)

3. For complete disintegration of the radionuclide:
$A = A_o(1.44 \times T_{eff})$

C. Specific Example

The following example is given solely to demonstrate the method of calculation and does not necessarily indicate that the target organs will receive the highest absorbed doses.

Example: 0.1 mCi ^{24}Na is administered orally and is excreted exponentially with a three hour biological half-life. What is the absorbed dose to the stomach? to the total body? (Simplifying assumption: idealized condition with no absorption of ^{24}Na from the stomach into the body).

1. Necessary Information on ^{24}Na in the Stomach
   a. Biological half-life (T_{bio}) = 3 h (given)
   b. Physical half-life (T_{phy}) = 15 h (p. 19, ref. 2)
   c. Calculated effective half-life:
      $\frac{1}{T_{eff}} = \frac{1}{3} + \frac{1}{15}$; $T_{eff} = 2.5$ h
2. Calculation of Cumulative Activity
   $\tilde{A} = A_o\,(1.44 \times T_{eff}) = 100\,(1.44 \times 2.5) = 360\ \mu$Ci-h
3. Determination of S factors from MIRD Pamphlet 11, p. 28–29.
   a. For source organ stomach content (stc) and target organ stomach wall (stw)
      $S(r_{stw} \leftarrow r_{stc}) = 3.6 \times 10^{-3}$ rads/μCi-hr
   b. For source organ stomach content (stc) and target total body (tb)
      $S(r_{tb} \leftarrow r_{stc}) = 4.9 \times 10^{-5}$ rads /μci-hr
4. Calculation of Dose to Target Organs from Source Organ
   a. $\bar{D}(r_{stw} \leftarrow r_{stc}) = 360\ \mu$Ci-hr $\times\ 3.6 \times 10^{-3}$ rads/μCi-hr = 1.30 rads
   b. $\bar{D}(r_{tb} \leftarrow r_{stc}) = 360\ \mu$Ci-hr $\times\ 4.9 \times 10^{-5}$ rads/μCi-r = .018 rads
5. Summary of Dose Calculations
   100 uCi ^{24}Na; Source Organ: Stomach

Target Organ	Absorbed Dose (rads)
Stomach	1.296
Total Body	0.018

References

1. Snyder, W. S., Ford, M. R., Warner, G. G., and Watson. S. B.: "S", Absorbed Dose per Unit Cumulated Activity for Selected Radionuclides and Organs. NM/MIRD Pamphlet No. 11, Society of Nuclear Medicine, 1975
2. Dillman, L. T., and Von der Lage, F. C. Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation NM/MIRD Pamphlet No. 10, Society of Nuclear Medicine 1975

Selected Decay Corrections

Calcium – 45

165 Days

Days	Days									
	0	2	4	6	8	10	12	14	16	18
0	1.0000	.9916	.9833	.9751	.9670	.9589	.9508	.9429	.9350	.9272
20	.9194	.9117	.9041	.8965	.8890	.8816	.8742	.8669	.8596	.8525
40	.8453	.8383	.8312	.8243	.8174	.8105	.8038	.7970	.7904	.7838
60	.7772	.7707	.7643	.7579	.7515	.7452	.7390	.7328	.7267	.7206
80	.7146	.7086	.7027	.6968	.6910	.6852	.6794	.6738	.6681	.6625
100	.6570	.6515	.6460	.6406	.6353	.6300	.6247	.6195	.6143	.6091
120	.6040	.5990	.5940	.5890	.5841	.5792	.5743	.5695	.5648	.5601
140	.5554	.5507	.5461	.5415	.5370	.5325	.5281	.5236	.5193	.5149
160	.5106	.5063	.5021	.4979	.4937	.4896	.4855	.4814	.4774	.4734
180	.4695	.4655	.4616	.4578	.4540	.4502	.4464	.4427	.4389	.4353
200	.4316	.4280	.4244	.4209	.4174	.4139	.4104	.4070	.4036	.4002
220	.3969	.3935	.3902	.3870	.3837	.3805	.3773	.3742	.3711	.3679
240	.3649	.3618	.3588	.3558	.3528	.3499	.3469	.3440	.3412	.3383
260	.3355	.3327	.3299	.3271	.3244	.3217	.3190	.3163	.3137	.3110
280	.3084	.3059	.3033	.3008	.2982	.2957	.2933	.2908	.2884	.2860
300	.2836	.2812	.2789	.2765	.2742	.2719	.2696	.2674	.2651	.2629
320	.2607	.2585	.2564	.2542	.2521	.2500	.2479	.2458	.2438	.2417
340	.2397	.2377	.2357	.2337	.2318	.2299	.2279	.2260	.2241	.2223
360	.2204	.2186	.2167	.2149	.2131	.2113	.2096	.2078	.2061	.2043

Calcium – 47

4.54 Days

Days	Hours											
	0	1	2	3	4	5	6	7	8	9	10	11
0.0	1.0000	.9937	.9874	.9811	.9749	.9687	.9626	.9564	.9504	.9444	.9384	.9324
0.5	.9265	.9206	.9148	.9090	.9032	.8975	.8918	.8862	.8805	.8749	.8694	.8639
1.0	.8584	.8530	.8476	.8422	.8368	.8315	.8263	.8210	.8158	.8106	.8055	.8004
1.5	.7953	.7903	.7853	.7803	.7753	.7704	.7655	.7607	.7559	.7511	.7463	.7416
2.0	.7369	.7322	.7275	.7229	.7184	.7138	.7093	.7048	.7003	.6959	.6914	.6871
2.5	.6827	.6784	.6741	.6698	.6656	.6613	.6571	.6530	.6488	.6447	.6406	.6366
3.0	.6325	.6285	.6245	.6206	.6166	.6127	.6088	.6050	.6011	.5973	.5935	.5898
3.5	.5860	.5823	.5786	.5750	.5713	.5677	.5641	.5605	.5570	.5534	.5499	.5464
4.0	.5430	.5395	.5361	.5327	.5293	.5260	.5226	.5193	.5160	.5128	.5095	.5063
4.5	.5031	.4999	.4967	.4936	.4904	.4873	.4842	.4812	.4781	.4751	.4721	.4691
5.0	.4661	.4631	.4602	.4573	.4544	.4515	.4486	.4458	.4430	.4402	.4374	.4346
5.5	.4318	.4291	.4264	.4237	.4210	.4183	.4157	.4130	.4104	.4078	.4052	.4026
6.0	.4001	.3976	.3950	.3925	.3900	.3876	.3851	.3827	.3802	.3778	.3754	.3731
6.5	.3707	.3683	.3660	.3637	.3614	.3591	.3568	.3545	.3523	.3501	.3478	.3456
7.0	.3434	.3413	.3391	.3370	.3348	.3327	.3306	.3285	.3264	.3243	.3223	.3202
7.5	.3182	.3162	.3142	.3122	.3102	.3082	.3063	.3043	.3024	.3005	.2986	.2967
8.0	.2948	.2929	.2911	.2892	.2874	.2856	.2838	.2820	.2802	.2784	.2766	.2749
8.5	.2731	.2714	.2697	.2680	.2663	.2646	.2629	.2613	.2596	.2579	.2563	.2547
9.0	.2531	.2515	.2499	.2483	.2467	.2451	.2436	.2421	.2405	.2390	.2375	.2360
9.5	.2345	.2330	.2315	.2300	.2286	.2271	.2257	.2243	.2228	.2214	.2200	.2186
10.0	.2172	.2159	.2145	.2131	.2118	.2104	.2091	.2078	.2065	.2052	.2038	.2026
10.5	.2013	.2000	.1987	.1975	.1962	.1950	.1937	.1925	.1913	.1901	.1889	.1877
11.0	.1865	.1853	.1841	.1830	.1818	.1806	.1795	.1784	.1772	.1761	.1750	.1739
11.5	.1728	.1717	.1706	.1695	.1684	.1674	.1663	.1652	.1642	.1632	.1621	.1611
12.0	.1601	.1591	.1581	.1570	.1561	.1551	.1541	.1531	.1521	.1512	.1502	.1493
12.5	.1483	.1474	.1464	.1455	.1446	.1437	.1428	.1419	.1410	.1401	.1392	.1383
13.0	.1374	.1365	.1357	.1348	.1340	.1331	.1323	.1314	.1306	.1298	.1289	.1281
13.5	.1273	.1265	.1257	.1249	.1241	.1233	.1225	.1218	.1210	.1202	.1195	.1187
14.0	.1180	.1172	.1165	.1157	.1150	.1143	.1135	.1128	.1121	.1114	.1107	.1100
14.5	.1093	.1086	.1079	.1072	.1065	.1059	.1052	.1045	.1039	.1032	.1025	.1019

Chromium – 51

27.8 Days

Days	Hours											
	0	2	4	6	8	10	12	14	16	18	20	22
0	1.0000	.9979	.9959	.9938	.9917	.9897	.9876	.9856	.9835	.9815	.9794	.9774
1	.9754	.9734	.9713	.9693	.9673	.9653	.9633	.9613	.9593	.9573	.9553	.9533
2	.9514	.9494	.9474	.9454	.9435	.9415	.9396	.9376	.9357	.9337	.9318	.9299
3	.9279	.9260	.9241	.9222	.9202	.9183	.9164	.9145	.9126	.9107	.9088	.9070
4	.9051	.9032	.9013	.8995	.8976	.8957	.8939	.8920	.8902	.8883	.8865	.8846
5	.8828	.8810	.8791	.8773	.8755	.8737	.8719	.8700	.8682	.8664	.8646	.8628
6	.8611	.8593	.8575	.8557	.8539	.8522	.8504	.8486	.8469	.8451	.8433	.8416
7	.8398	.8381	.8364	.8346	.8329	.8312	.8294	.8277	.8260	.8243	.8226	.8209
8	.8192	.8175	.8158	.8141	.8124	.8107	.8090	.8073	.8057	.8040	.8023	.8007
9	.7990	.7973	.7957	.7940	.7924	.7907	.7891	.7875	.7858	.7842	.7826	.7809
10	.7793	.7777	.7761	.7745	.7729	.7713	.7697	.7681	.7665	.7649	.7633	.7617
11	.7601	.7586	.7570	.7554	.7538	.7523	.7507	.7492	.7476	.7460	.7445	.7430
12	.7414	.7399	.7383	.7368	.7353	.7337	.7322	.7307	.7292	.7277	.7262	.7247
13	.7232	.7217	.7202	.7187	.7172	.7157	.7142	.7127	.7112	.7098	.7083	.7068
14	.7053	.7039	.7024	.7010	.6995	.6981	.6966	.6952	.6937	.6923	.6908	.6894
15	.6880	.6865	.6851	.6837	.6823	.6809	.6795	.6780	.6766	.6752	.6738	.6724
16	.6710	.6696	.6683	.6669	.6655	.6641	.6627	.6613	.6600	.6586	.6572	.6559
17	.6545	.6532	.6518	.6504	.6491	.6477	.6464	.6451	.6437	.6424	.6411	.6397
18	.6384	.6371	.6357	.6344	.6331	.6318	.6305	.6292	.6279	.6266	.6253	.6240
19	.6227	.6214	.6201	.6188	.6175	.6162	.6150	.6137	.6124	.6111	.6099	.6086
20	.6073	.6061	.6048	.6036	.6023	.6011	.5998	.5986	.5973	.5961	.5949	.5936
21	.5924	.5912	.5899	.5887	.5875	.5863	.5850	.5838	.5826	.5814	.5802	.5790
22	.5778	.5766	.5754	.5742	.5730	.5718	.5706	.5695	.5683	.5671	.5659	.5647
23	.5636	.5624	.5612	.5601	.5589	.5577	.5566	.5554	.5543	.5531	.5520	.5508
24	.5497	.5485	.5474	.5463	.5451	.5440	.5429	.5418	.5406	.5395	.5384	.5373
25	.5362	.5350	.5339	.5328	.5317	.5306	.5295	.5284	.5273	.5262	.5251	.5240
26	.5230	.5219	.5208	.5197	.5186	.5175	.5165	.5154	.5143	.5133	.5122	.5111
27	.5101	.5090	.5080	.5069	.5059	.5048	.5038	.5027	.5017	.5006	.4996	.4985
28	.4975	.4965	.4954	.4944	.4934	.4924	.4913	.4903	.4893	.4883	.4873	.4863
29	.4853	.4843	.4832	.4822	.4812	.4802	.4792	.4783	.4773	.4763	.4753	.4743

Cobalt – 57

270 Days

Days	Days									
	0	2	4	6	8	10	12	14	16	18
0	1.0000	.9949	.9898	.9847	.9797	.9747	.9697	.9647	.9598	.9548
20	.9500	.9451	.9402	.9354	.9306	.9259	.9211	.9164	.9117	.9071
40	.9024	.8978	.8932	.8886	.8841	.8795	.8750	.8706	.8661	.8617
60	.8572	.8529	.8485	.8441	.8398	.8355	.8312	.8270	.8227	.8185
80	.8143	.8102	.8060	.8019	.7978	.7937	.7896	.7856	.7816	.7776
100	.7736	.7696	7657	.7618	.7579	.7540	.7501	.7463	.7425	.7387
120	.7349	.7311	.7274	.7236	.7199	.7162	.7126	.7089	.7053	.7017
140	.6981	.6945	.6910	.6874	.6839	.6804	.6769	.6734	.6700	.6666
160	.6632	.6598	.6564	.6530	.6497	.6463	.6430	.6397	.6365	.6332
180	.6300	.6267	.6235	.6203	.6172	.6140	.6108	.6077	.6046	.6015
200	.5984	.5954	.5923	.5893	.5863	.5833	.5803	.5773	.5743	.5714
220	.5685	.5656	.5627	.5598	.5569	.5541	.5512	.5484	.5456	.5428
240	.5400	.5373	.5345	.5318	.5291	.5263	.5236	.5210	.5183	5156
260	.5130	5104	.5078	.5052	.5026	.5000	.4974	.4949	.4924	.4898
280	.4873	.4848	.4823	.4799	.4774	.4750	.4725	.4701	.4677	.4653
300	.4629	.4606	.4582	.4559	.4535	.4512	.4489	.4466	.4443	.4420
320	.4398	.4375	.4353	.4330	.4308	.4286	.4264	.4242	.4221	.4199
340	.4178	.4156	.4135	.4114	.4093	.4072	.4051	.4030	.4009	.3989
360	.3969	.3948	.3928	.3908	.3888	.3868	.3848	.3828	.3809	.3789
380	.3770	.3751	.3731	.3712	.3693	.3674	.3656	.3637	.3618	.3600
400	.3581	.3563	.3545	.3526	.3508	.3490	.3473	.3455	.3437	.3419
420	.3402	.3385	.3367	.3350	.3333	.3316	.3299	.3282	.3265	.3248
440	.3232	.3215	.3199	.3182	.3166	.3150	.3134	.3118	.3102	.3086
460	.3070	.3054	.3039	.3023	.3008	.2992	.2977	.2962	.2946	.2931
480	.2916	.2901	.2887	.2872	.2857	.2842	.2828	.2813	.2799	.2785

Fluorine – 18

109.7 Minutes

Minutes	Minutes									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9937	.9874	.9812	.9750	.9689	.9628	.9567	.9507	.9447
10	.9388	.9329	.9270	.9211	.9153	.9096	.9038	.8982	.8925	.8869
20	.8813	.8757	.8702	.8647	.8593	.8539	.8485	.8432	.8378	.8326
30	.8273	.8221	.8169	.8118	.8067	.8016	.7965	.7915	.7865	.7816
40	.7767	.7718	.7669	.7621	.7573	.7525	.7478	.7431	.7384	.7337
50	.7291	.7245	.7200	.7154	.7109	.7064	.7020	.6976	.6932	.6888
1 Hour	.6845	.6802	.6759	.6716	.6674	.6632	.6590	.6549	.6507	.6466
10	.6426	.6385	.6345	.6305	.6265	.6226	.6187	.6148	.6109	.6070
20	.6032	.5994	.5956	.5919	.5882	.5845	.5808	.5771	.5735	.5699
30	.5663	.5627	.5592	.5556	.5521	.5487	.5452	.5418	.5384	.5350
40	.5316	.5283	.5249	.5216	.5183	.5151	.5118	.5086	.5054	.5022
50	.4991	.4959	.4928	.4897	.4866	.4835	.4805	.4775	.4745	.4715
2 Hours	.4685	.4655	.4626	.4597	.4568	.4539	.4511	.4482	.4454	.4426
10	.4398	.4370	.4343	.4316	.4288	.4261	.4234	.4208	.4181	.4155
20	.4129	.4103	.4077	.4051	.4026	.4000	.3975	.3950	.3925	.3901
30	.3876	.3852	.3827	.3803	.3779	.3755	.3732	.3708	.3685	.3662
40	.3639	.3616	.3593	.3570	.3548	.3525	.3503	.3481	.3459	.3438
50	.3416	.3394	.3373	.3352	.3331	.3310	.3289	.3268	.3247	.3227
3 Hours	.3207	.3187	.3166	.3146	.3127	.3107	.3087	.3068	.3049	.3029
10	.3010	.2991	.2973	.2954	.2935	.2917	.2898	.2880	.2862	.2844
20	.2826	.2808	.2791	.2773	.2755	.2738	.2721	.2704	.2687	.2670
30	.2653	.2636	.2620	.2603	.2587	.2570	.2554	.2538	.2522	.2506
40	.2491	.2475	.2459	.2444	.2428	.2413	.2398	.2383	.2368	.2353
50	.2338	.2323	.2309	.2294	.2280	.2265	.2251	.2237	.2223	.2209
4 Hours	.2195	.2181	.2167	.2154	.2140	.2127	.2113	.2100	.2087	.2074
10	.2060	.2048	.2035	.2022	.2009	.1996	.1984	.1971	.1959	.1947
20	.1934	.1922	.1910	.1898	.1886	.1874	.1862	.1851	.1839	.1827
30	.1816	.1804	.1793	.1782	.1771	.1759	.1748	.1737	.1726	.1715
40	.1705	.1694	.1683	.1673	.1662	.1652	.1641	.1631	.1621	.1610
50	.1600	.1590	.1580	.1570	.1560	.1551	.1541	.1531	.1521	.1512
5 Hours	.1502	.1493	.1483	.1474	.1465	.1456	.1446	.1437	.1428	.1419
10	.1410	.1401	.1393	.1384	.1375	.1366	.1358	.1349	.1341	.1332
20	.1324	.1316	.1307	.1299	.1291	.1283	.1275	.1267	.1259	.1251
30	.1243	.1235	.1227	.1220	.1212	.1204	.1197	.1189	.1182	.1174
40	.1167	.1159	.1152	.1145	.1138	.1131	.1123	.1116	.1109	.1102
50	.1095	.1088	.1082	.1075	.1068	.1061	.1055	.1048	.1041	.1035
6 Hours	.1028	.1022	.1015	.1009	.1003	.0996	.0990	.0984	.0978	.0971

Gallium – 67

77.9 Hours

Hours	Hours											
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0	1.0000	.9956	.9911	.9867	.9824	.9780	.9737	.9693	.9650	.9608	.9565	.9522
6	.9480	.9438	.9396	.9354	.9313	.9272	.9230	.9189	.9149	.9108	.9068	.9027
12	.8987	.8947	.8908	.8868	.8829	.8790	.8751	.8712	.8673	.8635	.8596	.8558
18	.8520	.8482	.8445	.8407	.8370	.8333	.8296	.8259	.8222	.8186	.8149	.8113
1 Day	.8077	.8041	.8006	.7970	.7935	.7899	.7864	.7829	.7795	.7760	.7726	.7691
6	.7657	.7623	.7589	.7556	.7522	.7489	.7456	.7422	.7389	.7357	.7324	.7291
12	.7259	.7227	.7195	.7163	.7131	.7099	.7068	.7037	.7005	.6974	.6943	.6912
18	.6882	.6851	.6821	.6791	.6760	.6730	.6700	.6671	.6641	.6612	.6582	.6553
2 Days	.6524	.6495	.6466	.6437	.6409	.6380	.6352	.6324	.6296	.6268	.6240	.6212
6	.6185	.6157	.6130	.6103	.6076	.6049	.6022	.5995	.5969	.5942	.5916	.5889
12	.5863	.5837	.5811	.5786	.5760	.5734	.5709	.5684	.5658	.5633	.5608	.5583
18	.5558	.5534	.5509	.5485	.5460	.5436	.5412	.5388	.5364	.5340	.5317	.5293
3 Days	.5270	.5246	.5223	.5200	.5177	.5154	.5131	.5108	.5085	.5063	.5040	.5018
6	.4996	.4973	.4951	.4929	.4907	.4886	.4864	.4842	.4821	.4799	.4778	.4757
12	.4736	.4715	.4694	.4673	.4652	.4632	.4611	.4591	.4570	.4550	.4530	.4510
18	.4490	.4470	.4450	.4430	.4410	.4391	.4371	.4352	.4333	.4313	.4294	.4275
4 Days	.4256	.4237	.4219	.4200	.4181	.4163	.4144	.4126	.4107	.4089	.4071	.4053
6	.4035	.4017	.3999	.3981	.3964	.3946	.3929	.3911	.3894	.3877	.3859	.3842
12	.3825	.3808	.3791	.3774	.3758	.3741	.3724	.3708	.3691	.3675	.3659	.3643
18	.3626	.3610	.3594	.3578	.3562	.3547	.3531	.3515	.3500	.3484	.3469	.3453
5 Days	.3438	.3423	.3407	.3392	.3377	.3362	.3347	.3332	.3318	.3303	.3288	.3274
6	.3259	.3245	.3230	.3216	.3202	.3187	.3173	.3159	.3145	.3131	.3117	.3103
12	.3090	.3076	.3062	.3049	.3035	.3022	.3008	.2995	.2982	.2968	.2955	.2942
18	.2929	.2916	.2903	.2890	.2877	.2865	.2852	.2839	.2827	.2814	.2802	.2789
6 Days	.2777	.2764	.2752	.2740	.2728	.2716	.2704	.2692	.2680	.2668	.2656	.2644
6	.2632	.2621	.2609	.2598	.2586	.2574	.2563	.2552	.2540	.2529	.2518	.2507
12	.2496	.2484	.2473	.2462	.2452	.2441	.2430	.2419	.2408	.2398	.2387	.2376
18	.2366	.2355	.2345	.2334	.2324	.2314	.2304	.2293	.2283	.2273	.2263	.2253
7 Days	.2243	.2233	.2223	.2213	.2203	.2193	.2184	.2174	.2164	.2155	.2145	.2136

Gold – 198

2.697 Days

Hours	Hours											
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0	1.0000	.9947	.9893	.9841	.9788	.9736	.9684	.9632	.9581	.9530	.9479	.9428
6	.9378	.9328	.9278	.9228	.9179	.9130	.9081	.9033	.8984	.8937	.8889	.8841
12	.8794	.8747	.8700	.8654	.8608	.8562	.8516	.8471	.8425	.8380	.8336	.8291
18	.8247	.8203	.8159	.8115	.8072	.8029	.7986	.7943	.7901	.7859	7817	.7775
1 Day	.7734	.7692	.7651	.7610	.7570	.7529	.7489	.7449	.7409	.7370	.7330	.7291
6	.7252	.7214	.7175	.7137	.7099	.7061	.7023	.6986	.6948	.6911	.6874	.6838
12	.6801	.6765	.6729	.6693	.6657	.6621	.6586	.6551	.6516	.6481	.6446	.6412
18	.6378	.6344	.6310	.6276	.6243	.6209	.6176	.6143	.6110	.6078	.6045	.6013
2 Days	.5981	.5949	.5917	.5886	.5854	.5823	.5792	.5761	.5730	.5700	.5669	.5639
6	.5609	.5579	.5549	.5519	.5490	.5461	.5431	.5402	.5374	.5345	.5316	.5288
12	.5260	.5232	.5204	.5176	.5148	.5121	.5093	.5066	.5039	.5012	.4985	.4959
18	.4932	.4906	.4880	.4854	.4828	.4802	.4776	.4751	.4726	.4700	.4675	.4650
3 Days	.4625	.4601	.4576	.4552	.4527	.4503	.4479	.4455	.4431	.4408	.4384	.4361
6	.4338	.4314	.4291	.4268	.4246	.4223	.4200	.4178	.4156	.4133	.4111	.4089
12	.4068	.4046	.4024	.4003	.3981	.3960	.3939	.3918	.3897	.3876	.3856	.3835
18	.3815	.3794	.3774	.3754	.3734	.3714	.3694	.3674	.3655	3635	.3616	.3596
4 Days	.3577	.3558	.3539	.3520	.3501	.3483	.3464	.3446	.3427	.3409	.3391	.3373
6	.3355	.3337	.3319	.3301	.3283	.3266	.3248	.3231	.3214	.3197	.3180	.3163
12	.3146	.3129	.3112	.3096	.3079	.3063	.3046	.3030	.3014	.2998	.2982	.2966
18	.2950	.2934	.2919	.2903	.2887	.2872	.2857	.2841	.2826	.2811	.2796	.2781
5 Days	.2766	.2752	.2737	.2722	.2708	.2693	.2679	.2665	.2650	.2636	.2622	.2608
6	.2594	.2580	.2567	.2553	.2539	.2526	.2512	.2499	.2485	.2472	.2459	.2446
12	.2433	.2420	.2407	.2394	.2381	.2369	.2356	.2343	.2331	.2318	.2306	.2294
18	.2281	.2269	.2257	.2245	.2233	.2221	.2209	.2197	.2186	.2174	.2162	.2151
6 Days	.2139	.2128	.2117	.2105	.2094	.2083	.2072	.2061	.2050	.2039	.2028	.2017
6	.2006	.1996	.1985	.1974	.1964	.1953	.1943	.1932	.1922	.1912	.1902	.1892
12	.1881	.1871	.1861	.1851	.1842	.1832	.1822	.1812	.1803	.1793	.1783	.1774
18	.1764	.1755	.1746	.1736	.1727	.1718	.1709	.1699	.1690	.1681	.1672	.1663
7 Days	.1655	.1646	.1637	.1628	.1620	.1611	.1602	.1594	.1585	.1577	.1568	.1560

Hydrogen – 3

12.26 Years

Years	Months											
	0	1	2	3	4	5	6	7	8	9	10	11
0	1.0000	.9953	.9906	.9860	.9813	.9767	.9721	.9676	.9630	.9585	.9540	.9495
1	.9450	.9406	.9362	.9318	.9274	.9230	.9187	.9144	.9101	.9058	.9015	.8973
2	.8931	.8889	.8847	.8805	.8764	.8723	.8682	.8641	.8600	.8560	.8520	.8480
3	.8440	.8400	.8361	.8321	.8282	.8243	.8205	.8166	.8128	.8090	.8052	.8014
4	.7976	.7939	.7901	.7864	.7827	.7790	.7754	.7717	.7681	.7645	.7609	.7573
5	.7538	.7502	.7467	.7432	.7397	.7362	.7327	.7293	.7259	.7225	.7191	.7157
6	.7123	.7090	.7056	.7023	.6990	.6957	.6925	.6892	.6860	.6827	.6795	.6763
7	.6732	.6700	.6669	.6637	.6606	.6575	.6544	.6513	.6483	.6452	.6422	.6392
8	.6362	.6332	.6302	.6272	.6243	.6214	.6184	.6155	.6126	.6098	.6069	.6040
9	.6012	.5984	.5956	.5928	.5900	.5872	.5844	.5817	.5790	.5762	.5735	.5708

Iodine – 125

60.2 Days

Days	Days									
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.0000	.9943	.9886	.9829	.9772	.9716	.9660	.9605	.9550	.9495
5	.9441	.9386	.9332	.9279	.9226	.9173	.9120	.9068	.9016	.8964
10	.8912	.8861	.8810	.8760	.8710	.8660	.8610	.8560	.8511	.8462
15	.8414	.8366	.8317	.8270	.8222	.8175	.8128	.8081	.8035	.7989
20	.7943	.7898	.7852	.7807	.7762	.7718	.7673	.7629	.7586	.7542
25	.7499	.7456	.7413	.7370	.7328	.7286	.7244	.7203	.7161	.7120
1 Month	.7079	.7039	.6998	.6958	.6918	.6878	.6839	.6800	.6761	.6722
5	.6683	.6645	.6607	.6569	.6531	.6494	.6456	.6419	.6382	.6346
10	.6309	.6273	.6237	.6201	.6166	.6130	.6095	.6060	.6025	.5991
15	.5956	.5922	.5888	.5854	.5821	.5787	.5754	.5721	.5688	.5656
20	.5623	.5591	.5559	.5527	.5495	.5464	.5432	.5401	.5370	.5339
25	.5309	.5278	.5248	.5218	.5188	.5158	.5128	.5099	.5070	.5040
2 Months	.5012	.4983	.4954	.4926	.4897	.4869	.4841	.4814	.4786	.4758
5	.4731	.4704	.4677	.4650	.4623	.4597	.4571	.4544	.4518	.4492
10	.4466	.4441	.4415	.4390	.4365	.4340	.4315	.4290	.4265	.4241
15	.4217	.4192	.4168	.4144	.4121	.4097	.4073	.4050	.4027	.4004
20	.3981	.3958	.3935	.3913	.3890	.3868	.3846	.3823	.3802	.3780
25	.3758	.3736	.3715	.3694	.3672	.3651	.3630	.3610	.3589	.3568
3 Months	.3548	.3527	.3507	.3487	.3467	.3447	.3427	.3408	.3388	.3369
5	.3349	.3330	.3311	.3292	.3273	.3254	.3236	.3217	.3199	.3180
10	.3162	.3144	.3126	.3108	.3090	.3072	.3055	.3037	.3020	.3002
15	.2985	.2968	.2951	.2934	.2917	.2900	.2884	.2867	.2851	.2834
20	.2818	.2802	.2786	.2770	.2754	.2738	.2722	.2707	.2691	.2676
25	.2660	.2645	.2630	.2615	.2600	.2585	.2570	.2555	.2541	.2526
4 Months	.2512	.2497	.2483	.2469	.2454	.2440	.2426	.2412	.2398	.2385

Iodine – 131

8.05 Days

Days	Hours											
	0	1	2	3	4	5	6	7	8	9	10	11
0.0	1.0000	.9964	.9929	.9893	.9858	.9822	.9787	.9752	.9717	.9682	.9648	.9613
0.5	.9579	.9544	.9510	.9476	.9442	.9408	.9375	.9341	.9308	.9274	.9241	.9208
1.0	.9175	.9142	.9109	.9077	.9044	.9012	.8980	.8947	.8915	.8883	.8852	.8820
1.5	.8788	.8757	.8726	.8694	.8663	.8632	.8601	.8570	.8540	.8509	.8479	.8448
2.0	.8418	.8388	.8358	.8328	.8298	.8268	.8239	.8209	.8180	.8151	.8121	.8092
2.5	.8063	.8034	.8006	.7977	.7948	.7920	.7892	.7863	.7835	.7807	.7779	.7751
3.0	.7724	.7696	.7668	.7641	.7613	.7586	.7559	.7532	.7505	.7478	.7451	.7425
3.5	.7398	.7372	.7345	.7319	.7293	.7267	.7241	.7215	.7189	.7163	.7137	.7112
4.0	.7086	.7061	.7036	.7010	.6985	.6960	.6935	.6911	.6886	.6861	.6837	.6812
4.5	.6788	.6763	.6739	.6715	.6691	.6667	.6643	.6619	.6596	.6572	.6548	.6525
5.0	.6502	.6478	.6455	.6432	.6409	.6386	.6363	.6340	.6318	.6295	.6273	.6250
5.5	.6228	.6205	.6183	.6161	.6139	.6117	.6095	.6073	.6051	.6030	.6008	.5987
6.0	.5965	.5944	.5923	.5901	.5880	.5859	.5838	.5817	.5796	.5776	.5755	.5734
6.5	.5714	.5693	.5673	.5653	.5632	.5612	.5592	.5572	.5552	.5532	.5513	.5493
7.0	.5473	.5454	.5434	.5415	.5395	.5376	.5357	.5337	.5318	.5299	.5280	.5261
7.5	.5242	.5224	.5205	.5186	.5168	.5149	.5131	.5112	.5094	.5076	.5058	.5040
8.0	.5022	.5004	.4986	.4968	.4950	.4932	.4915	.4897	.4879	.4862	.4845	.4827
8.5	.4810	.4793	.4776	.4758	.4741	.4724	.4708	.4691	.4674	.4657	.4640	.4624
9.0	.4607	.4591	.4574	.4558	.4542	.4525	.4509	.4493	.4477	.4461	.4445	.4429
9.5	.4413	.4397	.4382	.4366	.4350	.4335	.4319	.4304	.4288	.4273	.4258	.4242
10.0	.4227	.4212	.4197	.4182	.4167	.4152	.4137	.4122	.4108	.4093	.4078	.4064
10.5	.4049	.4035	.4020	.4006	.3991	.3977	.3963	.3949	.3934	.3920	.3906	.3892
11.0	.3878	.3865	.3851	.3837	.3823	.3809	.3796	.3782	.3769	.3755	.3742	.3728
11.5	.3715	.3702	.3688	.3675	.3662	.3649	.3636	.3623	.3610	.3597	.3584	.3571
12.0	.3558	.3546	.3533	.3520	.3508	.3495	.3483	.3470	.3458	.3445	.3433	.3421
12.5	.3408	.3396	.3384	.3372	.3360	.3348	.3336	.3324	.3312	.3300	.3288	.3277
13.0	.3265	.3253	.3242	.3230	.3218	.3207	.3195	.3184	.3172	.3161	.3150	.3139
13.5	.3127	.3116	.3105	.3094	.3083	.3072	.3061	.3050	.3039	.3028	.3017	.3006
14.0	.2996	.2985	.2974	.2963	.2953	.2942	.2932	.2921	.2911	.2900	.2890	.2880
14.5	.2869	.2859	.2849	.2839	.2828	.2818	.2808	.2798	.2788	.2778	.2768	.2758

Iron – 55

2.60 Years

Months	Weeks											
	0	1	2	3	4	5	6	7	8	9	10	11
0	1.0000	.9949	.9898	.9847	.9797	.9747	.9697	.9647	.9598	.9549	.9500	.9452
3	.9403	.9355	.9307	.9260	.9212	.9165	.9118	.9072	.9025	.8979	.8933	.8888
6	.8842	.8797	.8752	.8707	.8663	.8618	.8574	.8531	.8487	.8444	.8400	.8357
9	.8315	.8272	.8230	.8188	.8146	.8104	.8063	.8022	.7981	.7940	.7899	.7859
1 Year	.7819	.7779	.7739	.7699	.7660	.7621	.7582	.7543	.7504	.7466	.7428	.7390
3	.7352	.7314	.7277	.7240	.7203	.7166	.7129	.7093	.7057	.7020	.6985	.6949
6	.6913	.6878	.6843	.6808	.6773	.6738	.6704	.6670	.6636	.6602	.6568	.6534
9	.6501	.6468	.6435	.6402	.6369	.6336	.6304	.6272	.6240	.6208	.6176	.6144
2 Years	.6113	.6082	.6051	.6020	.5989	.5958	.5928	.5897	.5867	.5837	.5807	.5778
3	.5748	.5719	.5690	.5660	.5632	.5603	.5574	.5546	.5517	.5489	.5461	.5433
6	.5405	.5378	.5350	.5323	.5296	.5268	.5241	.5215	.5188	.5161	.5135	.5109
9	.5083	.5057	.5031	.5005	.4980	.4954	.4929	.4904	.4878	.4854	.4829	.4804
3 Years	.4779	.4755	.4731	.4706	.4682	.4658	.4635	.4611	.4587	.4564	.4541	.4517
3	.4494	.4471	.4448	.4426	.4403	.4381	.4358	.4336	.4314	.4292	.4270	.4248
6	.4226	.4204	.4183	.4162	.4140	.4119	.4098	.4077	.4056	.4036	.4015	.3994
9	.3974	.3954	.3933	.3913	.3893	.3873	.3854	.3834	.3814	.3795	.3775	.3756
4 Years	.3737	.3718	.3699	.3680	.3661	.3642	.3624	.3605	.3587	.3568	.3550	.3532
3	.3514	.3496	.3478	.3460	.3443	.3425	.3407	.3390	.3373	.3355	.3338	.3321
6	.3304	.3287	.3270	.3254	.3237	.3221	.3204	.3188	.3171	.3155	.3139	.3123
9	.3107	.3091	.3075	.3060	.3044	.3028	.3013	.2998	.2982	.2967	.2952	.2937
5 Years	.2922	.2907	.2892	.2877	.2862	.2848	.2833	.2819	.2804	.2790	.2776	.2761
3	.2747	.2733	.2719	.2705	.2692	.2678	.2664	.2650	.2637	.2623	.2610	.2597
6	.2583	.2570	.2557	.2544	.2531	.2518	.2505	.2492	.2480	.2467	.2454	.2442
9	.2429	.2417	.2404	.2392	.2380	.2368	.2356	.2344	.2332	.2320	.2308	.2296
6 Years	.2284	.2273	.2261	.2249	.2238	.2226	.2215	.2204	.2193	.2181	.2170	.2159

Iron – 59

45.6 Days

Days	Hours											
	0	6	12	18	24	30	36	42	48	54	60	66
0	1.0000	.9962	.9924	.9887	.9849	.9812	.9775	.9737	.9701	.9664	.9627	.9591
3	.9554	.9518	.9482	.9446	.9410	.9374	.9339	.9303	.9268	.9233	.9198	.9163
6	.9128	.9094	.9059	.9025	.8891	.8957	.8923	.8889	.8855	.8821	.8788	.8755
9	.8721	.8688	.8655	.8623	.8590	.8557	.8525	.8492	.8460	.8428	.8396	.8364
12	.8333	.8301	.8270	.8238	.8207	.8176	.8145	.8114	.8083	.8052	.8022	.7991
15	.7961	.7931	.7901	.7871	.7841	.7811	.7782	.7752	.7723	.7693	.7664	.7635
18	.7606	.7577	.7549	.7520	.7492	.7463	.7435	.7407	.7379	.7351	.7323	.7295
21	.7267	.7240	.7212	.7185	.7158	.7130	.7103	.7076	.7050	.7023	.6996	.6970
24	.6943	.6917	.6891	.6865	.6839	.6813	.6787	.6761	.6735	.6710	.6684	.6659
27	.6634	.6609	.6584	.6559	.6534	.6509	.6484	.6460	.6435	.6411	.6386	.6362
1 Month	.6338	.6314	.6290	.6266	.6242	.6219	.6195	.6172	.6148	.6125	.6102	.6079
3	.6055	.6033	.6010	.5987	.5964	.5942	.5919	.5897	.5874	.5852	.5830	.5808
6	.5786	.5764	.5742	.5720	.5698	.5677	.5655	.5634	.5612	.5591	.5570	.5549
9	.5528	.5507	.5486	.5465	.5444	.5424	.5403	.5383	.5362	.5342	.5322	.5301
12	.5281	.5261	.5241	.5221	.5202	.5182	.5162	.5143	.5123	.5104	.5084	.5065
15	.5046	.5027	.5008	.4989	.4970	.4951	.4932	.4913	.4895	.4876	.4858	.4839
18	.4821	.4803	.4784	.4766	.4748	.4730	.4712	.4694	.4677	.4659	.4641	.4624
21	.4606	.4589	.4571	.4554	.4536	.4519	.4502	.4485	.4468	.4451	.4434	.4417
24	.4401	.4384	.4367	.4351	.4334	.4318	.4301	.4285	.4269	.4253	.4237	.4220
27	.4204	.4189	.4173	.4157	.4141	.4125	.4110	.4094	.4079	.4063	.4048	.4032
2 Months	.4017	.4002	.3987	.3972	.3956	.3941	.3926	.3912	.3897	.3882	.3867	.3853
3	.3838	.3823	.3809	.3794	.3780	.3766	.3751	.3737	.3723	.3709	.3695	.3681
6	.3667	.3653	.3639	.3625	.3612	.3598	.3584	.3571	.3557	.3544	.3530	.3517
9	.3503	.3490	.3477	.3464	.3451	.3437	.3424	.3411	.3399	.3386	.3373	.3360
12	.3347	.3335	.3322	.3309	.3297	.3284	.3272	.3259	.3247	.3235	.3222	.3210
15	.3198	.3186	.3174	.3162	.3150	.3138	.3126	.3114	.3102	.3091	.3079	.3067
18	.3055	.3044	.3032	.3021	.3009	.2998	.2987	.2975	.2964	.2953	.2942	.2930
21	.2919	.2908	.2897	.2886	.2875	.2864	.2853	.2843	.2832	.2821	.2810	.2800
24	.2789	.2779	.2768	.2758	.2747	.2737	.2726	.2716	.2706	.2695	.2685	.2675
27	.2665	.2655	.2645	.2635	.2625	.2615	.2605	.2595	.2585	.2575	.2565	.2556

Mercury – 197

Hours	Hours											
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0	1.0000	.9947	.9894	.9841	.9789	.9737	.9685	.9634	.9582	.9531	.9481	.9430
6	.9380	.9330	.9281	.9231	.9182	.9133	.9085	.9037	.8989	.8941	.8893	.8846
12	.8799	.8752	.8706	.8659	.8613	.8567	.8522	.8476	.8431	.8387	.8342	.8298
18	.8253	.8210	.8166	.8123	.8079	.8036	.7994	.7951	.7909	.7867	.7825	.7783
1 Day	.7742	.7701	.7660	.7619	.7579	.7538	.7498	.7458	.7419	.7379	.7340	.7301
6	.7262	.7223	.7185	.7147	.7109	.7071	.7033	.6996	.6959	.6922	.6885	.6848
12	.6812	.6776	.6740	.6704	.6668	.6633	.6598	.6562	.6528	.6493	.6458	.6424
18	.6390	.6356	.6322	.6288	.6255	.6222	.6189	.6156	.6123	.6090	.6058	.6026
2 Days	.5994	.5962	.5930	.5899	.5867	.5836	.5805	.5774	.5743	.5713	.5683	.5652
6	.5622	.5592	.5563	.5533	.5504	.5474	.5445	.5416	.5388	.5359	.5330	.5302
12	.5274	.5246	.5218	.5190	.5163	.5135	.5108	.5081	.5054	.5027	.5000	.4973
18	.4947	.4921	.4894	.4868	.4843	.4817	.4791	.4766	.4740	.4715	.4690	.4665
3 Days	.4640	.4616	.4591	.4567	.4542	.4518	.4494	.4470	.4447	.4423	.4399	.4376
6	.4353	.4330	.4307	.4284	.4261	.4238	.4216	.4193	.4171	.4149	.4127	.4105
12	.4083	.4061	.4040	.4018	.3997	.3976	.3954	.3933	.3912	.3892	.3871	.3850
18	.3830	.3810	.3789	.3769	.3749	.3729	.3709	.3690	.3670	.3650	.3631	.3612
4 Days	.3593	.3573	.3554	.3536	.3517	.3498	.3479	.3461	.3443	.3424	.3406	.3388
6	.3370	.3352	.3334	.3316	.3299	.3281	.3264	.3246	.3229	.3212	.3195	.3178
12	.3161	.3144	.3127	.3111	.3094	.3078	.3061	.3045	.3029	.3013	.2997	.2981
18	.2965	.2949	.2934	.2918	.2903	.2887	.2872	.2856	.2841	.2826	.2811	.2796
5 Days	.2781	.2767	.2752	.2737	.2723	.2708	.2694	.2679	.2665	.2651	.2637	.2623
6	.2609	.2595	.2581	.2568	.2554	.2540	.2527	.2513	.2500	.2487	.2473	.2460
12	.2447	.2434	.2421	.2408	.2396	.2383	.2370	.2358	.2345	.2333	.2320	.2308
18	.2296	.2283	.2271	.2259	.2247	.2235	.2223	.2211	.2200	.2188	.2176	.2165
6 Days	.2153	.2142	.2130	.2119	.2108	.2097	.2085	.2074	.2063	.2052	.2041	.2031
6	.2020	.2009	.1998	.1988	.1977	.1967	.1956	.1946	.1935	.1925	.1915	.1905
12	.1895	.1885	.1875	.1865	.1855	.1845	.1835	.1825	.1816	.1806	.1796	.1787
18	.1777	.1768	.1758	.1749	.1740	.1730	.1721	.1712	.1703	.1694	.1685	.1676
7 Days	.1667	.1658	.1649	.1641	.1632	.1623	.1615	.1606	.1597	.1589	.1581	.1572

Phosphorus – 32

14.28 Days

Days	Hours											
	0	2	4	6	8	10	12	14	16	18	20	22
0	1.0000	.9960	.9919	.9879	.9840	.9800	.9760	.9721	.9682	.9642	.9604	.9565
1	.9526	.9488	.9449	.9411	.9373	.9335	.9298	.9260	.9223	.9186	.9149	.9112
2	.9075	.9038	.9002	.8965	.8929	.8893	.8857	.8821	.8786	.8750	.8715	.8680
3	.8645	.8610	.8575	.8541	.8506	.8472	.8438	.8404	.8370	.8336	.8302	.8269
4	.8235	.8202	.8169	.8136	.8103	.8070	.8038	.8005	.7973	.7941	.7909	.7877
5	.7845	.7813	.7782	.7750	.7719	.7688	.7657	.7626	.7595	.7565	.7534	.7504
6	.7473	.7443	.7413	.7383	.7353	.7324	.7294	.7265	.7235	.7206	.7177	.7148
7	.7119	.7091	.7062	.7033	.7005	.6977	.6949	.6921	.6893	.6865	.6837	.6809
8	.6782	.6755	.6727	.6700	.6673	.6646	.6619	.6593	.6566	.6540	.6513	.6437
9	.6461	.6435	.6409	.6383	.6357	.6331	.6306	.6280	.6255	.6230	.6205	.6179
10	.6155	.6130	.6105	.6080	.6056	.6031	.6007	.5983	.5959	.5935	.5911	.5887
11	.5863	.5839	.5816	.5792	.5769	.5746	.5722	.5699	.5676	.5653	.5631	.5608
12	.5585	.5563	.5540	.5518	.5495	.5473	.5451	.5429	.5407	.5385	.5364	.5342
13	.5321	.5299	.5278	.5256	.5235	.5214	.5193	.5172	.5151	.5130	.5110	.5089
14	.5068	.5048	.5028	.5007	.4987	.4967	.4947	.4927	.4907	.4887	.4867	.4848
15	.4828	.4809	.4789	.4770	.4751	.4732	.4713	.4693	.4675	.4656	.4637	.4618
16	.4600	.4581	.4562	.4544	.4526	.4507	.4489	.4471	.4453	.4435	.4417	.4399
17	.4382	.4364	.4346	.4329	.4311	.4294	.4277	.4259	.4242	.4225	.4208	.4191
18	.4174	.4157	.4140	.4124	.4107	.4090	.4074	.4057	.4041	.4025	.4009	.3992
19	.3976	.3960	.3944	.3928	.3912	.3897	.3881	.3865	.3850	.3834	.3819	.3803
20	.3788	.3773	.3757	.3742	.3727	.3712	.3697	.3682	.3667	.3652	.3638	.3623
21	.3608	.3594	.3579	.3565	.3550	.3536	.3522	.3508	.3493	.3479	.3465	.3451
22	.3437	.3424	.3410	.3396	.3382	.3369	.3355	.3341	.3328	.3314	.3301	.3288
23	.3275	.3261	.3248	.3235	.3222	.3209	.3196	.3183	.3170	.3157	.3145	.3132
24	.3119	.3107	.3094	.3082	.3069	.3057	.3045	.3032	.3020	.3008	.2996	.2984
25	.2972	.2960	.2948	.2936	.2924	.2912	.2900	.2889	.2877	.2865	.2854	.2842
26	.2831	.2819	.2808	.2797	.2785	.2774	.2763	.2752	.2741	.2730	.2719	.2708
27	.2697	.2686	.2675	.2664	.2653	.2643	.2632	.2621	.2611	.2600	.2590	.2579
28	.2569	.2559	.2548	.2538	.2528	.2517	.2507	.2497	.2487	.2477	.2467	.2457
29	.2447	.2437	.2427	.2418	.2408	.2398	.2388	.2379	.2369	.2360	.2350	.2341

Phosphorus – 33

24.4 Days

Days	Hours											
	0	2	4	6	8	10	12	14	16	18	20	22
0	1.0000	.9976	.9953	.9929	.9906	.9882	.9859	.9836	.9812	.9789	.9766	.9743
1	.9720	.9697	.9674	.9651	.9628	.9606	.9583	.9560	.9538	.9515	.9493	.9470
2	.9448	.9425	.9403	.9381	.9359	.9337	.9314	.9292	.9270	.9249	.9227	.9205
3	.9183	.9161	.9140	.9118	.9097	.9075	.9054	.9032	.9011	.8989	.8968	.8947
4	.8926	.8905	.8884	.8863	.8842	.8821	.8800	.8779	.8758	.8738	.8717	.8696
5	.8676	.8655	.8635	.8614	.8594	.8574	.8554	.8533	.8513	.8493	.8473	.8453
6	.8433	.8413	.8393	.8373	.8353	.8334	.8314	.8294	.8275	.8255	.8236	.8216
7	.8197	.8177	.8158	.8139	.8119	.8100	.8081	.8062	.8043	.8024	.8005	.7986
8	.7967	.7948	.7929	.7911	.7892	.7873	.7855	.7836	.7818	.7799	.7781	.7762
9	.7744	.7726	.7707	.7689	.7671	.7653	.7635	.7617	.7599	.7581	.7563	.7545
10	.7527	.7509	.7492	.7474	.7456	.7439	.7421	.7403	.7386	.7368	.7351	.7334
11	.7316	.7299	.7282	.7264	.7247	.7230	.7213	.7196	.7179	.7162	.7145	.7128
12	.7111	.7095	.7078	.7061	.7044	.7028	.7011	.6994	.6978	.6961	.6945	.6929
13	.6912	.6896	.6880	.6863	.6847	.6831	.6815	.6799	.6783	.6766	.6750	.6735
14	.6719	.6703	.6687	.6671	.6655	.6640	.6624	.6608	.6593	.6577	.6561	.6546
15	.6530	.6515	.6500	.6484	.6469	.6454	.6438	.6423	.6408	.6393	.6378	.6363
16	.6348	.6332	.6318	.6303	.6288	.6273	.6258	.6243	.6228	.6214	.6199	.6184
17	.6170	.6155	.6141	.6126	.6112	.6097	.6083	.6068	.6054	.6040	.6025	.6011
18	.5997	.5983	.5969	.5954	.5940	.5926	.5912	.5898	.5884	.5871	.5857	.5843
19	.5829	.5815	.5801	.5788	.5774	.5760	.5747	.5733	.5720	.5706	.5693	.5679
20	.5666	.5652	.5639	.5626	.5612	.5599	.5586	.5573	.5559	.5546	.5533	.5520
21	.5507	.5494	.5481	.5468	.5455	.5442	.5429	.5417	.5404	.5391	.5378	.5365
22	.5353	.5340	.5327	.5315	.5302	.5290	.5277	.5265	.5252	.5240	.5228	.5215
23	.5203	.5191	.5178	.5166	.5154	.5142	.5129	.5117	.5105	.5093	.5081	.5069
24	.5057	.5045	.5033	.5021	.5009	.4998	.4986	.4974	.4962	.4951	.4939	.4927
25	.4915	.4904	.4892	.4881	.4869	.4858	.4846	.4835	.4823	.4812	.4801	.4789
26	.4778	.4767	.4755	.4744	.4733	.4722	.4710	.4699	.4688	.4677	.4666	.4655
27	.4644	.4633	.4622	.4611	.4600	.4589	.4579	.4568	.4557	.4546	.4535	.4525
28	.4514	.4503	.4493	.4482	.4471	.4461	.4450	.4440	.4429	.4419	.4408	.4398
29	.4388	.4377	.4367	.4356	.4346	.4336	.4326	.4315	.4305	.4295	.4285	.4275
30	.4265	.4255	.4244	.4234	.4224	.4214	.4204	.4195	.4185	.4175	.4165	.4155
31	.4145	.4135	.4126	.4116	.4106	.4096	.4087	.4077	.4067	.4058	.4048	.4039
32	.4029	.4020	.4010	.4001	.3991	.3982	.3972	.3963	.3953	.3944	.3935	.3926
33	.3916	.3907	.3898	.3889	.3879	.3870	.3861	.3852	.3843	.3834	.3825	.3816
34	.3807	.3798	.3789	.3780	.3771	.3762	.3753	.3744	.3735	.3726	.3717	.3709

Potassium – 42

12.36 Hours

Hours	Minutes											
	0	5	10	15	20	25	30	35	40	45	50	55
0	1.0000	.9953	.9907	.9861	.9815	.9769	.9723	.9678	.9633	.9588	.9543	.9499
1	.9455	.9411	.9367	.9323	.9280	.9236	.9193	.9150	.9108	.9065	.9023	.8981
2	.8939	.8897	.8856	.8815	.8773	.8733	.8692	.8651	.8611	.8571	.8531	.8491
3	.8452	.8412	.8373	.8334	.8295	.8256	.8218	.8180	.8141	.8103	.8066	.8028
4	.7991	.7953	.7916	.7879	.7843	.7806	.7770	.7733	.7697	.7661	.7626	.7590
5	.7555	.7520	.7485	.7450	.7415	.7380	.7346	.7312	.7278	.7244	.7210	.7176
6	.7143	.7110	.7076	.7043	.7011	.6978	.6945	.6913	.6881	.6849	.6817	.6785
7	.6753	.6722	.6690	.6659	.6628	.6597	.6567	.6536	.6505	.6475	.6445	.6415
8	.6385	.6355	.6326	.6296	.6267	.6238	.6208	.6179	.6151	.6122	.6093	.6065
9	.6037	.6009	.5981	.5953	.5925	.5897	.5870	.5842	.5815	.5788	.5761	.5734
10	.5708	.5681	.5654	.5628	.5602	.5576	.5550	.5524	.5498	.5472	.5447	.5422
11	.5396	.5371	.5346	.5321	.5296	.5272	.5247	.5223	.5198	.5174	.5150	.5126
12	.5102	.5078	.5055	.5031	.5007	.4984	.4961	.4938	.4915	.4892	.4869	.4846
13	.4824	.4801	.4779	.4757	.4734	.4712	.4690	.4668	.4647	.4625	.4603	.4582
14	.4561	.4539	.4518	.4497	.4476	.4455	.4435	.4414	.4393	.4373	.4352	.4332
15	.4312	.4292	.4272	.4252	.4232	.4212	.4193	.4173	.4154	.4134	.4115	.4096
16	.4077	.4058	.4039	.4020	.4001	.3983	.3964	.3946	.3927	.3909	.3891	.3873
17	.3854	.3836	.3819	.3801	.3783	.3765	.3748	.3730	.3713	.3696	.3678	.3661
18	.3644	.3627	.3610	.3594	.3577	.3560	.3543	.3527	.3511	.3494	.3478	.3462
19	.3445	.3429	.3413	.3398	.3382	.3366	.3350	.3335	.3319	.3304	.3288	.3273
20	.3258	.3242	.3227	.3212	.3197	.3182	.3168	.3153	.3138	.3123	.3109	.3094
21	.3080	.3066	.3051	.3037	.3023	.3009	.2995	.2981	.2967	.2953	.2939	.2926
22	.2912	.2898	.2885	.2871	.2858	.2845	.2831	.2818	.2805	.2792	.2779	.2766
23	.2753	.2740	.2728	.2715	.2702	.2690	.2677	.2665	.2652	.2640	.2627	.2615
24	.2603	.2591	.2579	.2567	.2555	.2543	.2531	.2519	.2507	.2496	.2484	.2473

Potassium – 43

22.4 Hours

Hours	Minutes											
	0	10	20	30	40	50	60	70	80	90	100	110
0	1.0000	.9949	.9897	.9846	.9796	.9745	.9695	.9645	.9596	.9546	.9497	.9448
2	.9400	.9352	.9303	.9256	.9208	.9161	.9113	.9067	.9020	.8974	.8927	.8881
4	.8836	.8790	.8745	.8700	.8655	.8611	.8567	.8522	.8479	.8435	.8392	.8348
6	.8306	.8263	.8220	.8178	.8136	.8094	.8052	.8011	.7970	.7929	.7888	.7847
8	.7807	.7767	.7727	.7687	.7648	.7608	.7569	.7530	.7492	.7453	.7415	.7377
10	.7339	.7301	.7263	.7226	.7189	.7152	.7115	.7078	.7042	.7006	.6970	.6934
12	.6898	.6863	.6827	.6792	.6757	.6723	.6688	.6654	.6619	.6585	.6551	.6518
14	.6484	.6451	.6418	.6385	.6352	.6319	.6287	.6254	.6222	.6190	.6158	.6127
16	.6095	.6064	.6033	.6001	.5971	.5940	.5909	.5879	.5849	.5819	.5789	.5759
18	.5729	.5700	.5670	.5641	.5612	.5583	.5555	.5526	.5498	.5469	.5441	.5413
20	.5385	.5358	.5330	.5303	.5276	.5248	.5221	.5195	.5168	.5141	.5115	.5088
22	.5062	.5036	.5010	.4985	.4959	.4933	.4908	.4883	.4858	.4833	.4808	.4783
1 Day	.4758	.4734	.4710	.4685	.4661	.4637	.4613	.4590	.4566	.4543	.4519	.4496
2	.4473	.4450	.4427	.4404	.4382	.4359	.4337	.4314	.4292	.4270	.4248	.4226
4	.4204	.4183	.4161	.4140	.4119	.4097	.4076	.4055	.4035	.4014	.3993	.3973
6	.3952	.3932	.3912	.3891	.3871	.3852	.3832	.3812	.3792	.3773	.3754	.3734
8	.3715	.3696	.3677	.3658	.3639	.3620	.3602	.3583	.3565	.3546	.3528	.3510
10	.3492	.3474	.3456	.3438	.3421	.3403	.3386	.3368	.3351	.3334	.3317	.3299
12	.3282	.3266	.3249	.3232	.3215	.3199	.3182	.3166	.3150	.3134	.3117	.3101
14	.3085	.3070	.3054	.3038	.3022	.3007	.2991	.2976	.2961	.2946	.2930	.2915
16	.2900	.2885	.2871	.2856	.2841	.2826	.2812	.2797	.2783	.2769	.2755	.2740
18	.2726	.2712	.2698	.2684	.2671	.2657	.2643	.2630	.2616	.2603	.2589	.2576
20	.2563	.2549	.2536	.2523	.2510	.2497	.2485	.2472	.2459	.2446	.2434	.2421
22	.2409	.2396	.2384	.2372	.2360	.2348	.2335	.2323	.2312	.2300	.2288	.2276
2 Days	.2264	.2253	.2241	.2230	.2218	.2207	.2195	.2184	.2173	.2162	.2150	.2139

Selenium – 75

120.4 Days

Days	Days									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9943	.9886	.9829	.9772	.9716	.9660	.9605	.9550	.9495
10	.9441	.9386	.9332	.9279	.9226	.9173	.9120	.9068	.9016	.8964
20	.8912	.8861	.8810	.8760	.8710	.8660	.8610	.8560	.8511	.8462
1 Month	.8414	.8366	.8317	.8270	.8222	.8175	.8128	.8081	.8035	.7989
10	.7943	.7898	.7852	.7807	.7762	.7718	.7673	.7629	.7586	.7542
20	.7499	.7456	.7413	.7370	.7328	.7286	.7244	.7203	.7161	.7120
2 Months	.7079	.7039	.6998	.6958	.6918	.6878	.6839	.6800	.6761	.6722
10	.6683	.6645	.6607	.6569	.6531	.6494	.6456	.6419	.6382	.6346
20	.6309	.6273	.6237	.6201	.6166	.6130	.6095	.6060	.6025	.5991
3 Months	.5956	.5922	.5888	.5854	.5821	.5787	.5754	.5721	.5688	.5656
10	.5623	.5591	.5559	.5527	.5495	.5464	.5432	.5401	.5370	.5339
20	.5309	.5278	.5248	.5218	.5188	.5158	.5128	.5099	.5070	.5040
4 Months	.5012	.4983	.4954	.4926	.4897	.4869	.4841	.4814	.4786	.4758
10	.4731	.4704	.4677	.4650	.4623	.4597	.4571	.4544	.4518	.4492
20	.4466	.4441	.4415	.4390	.4365	.4340	.4315	.4290	.4265	.4241
5 Months	.4217	.4192	.4168	.4144	.4121	.4097	.4073	.4050	.4027	.4004
10	.3981	.3958	.3935	.3913	.3890	.3868	.3846	.3823	.3802	.3780
20	.3758	.3736	.3715	.3694	.3672	.3651	.3630	.3610	.3589	.3568
6 Months	.3548	.3527	.3507	.3487	.3467	.3447	.3427	.3408	.3388	.3369
10	.3349	.3330	.3311	.3292	.3273	.3254	.3236	.3217	.3199	.3180
20	.3162	.3144	.3126	.3108	.3090	.3072	.3055	.3037	.3020	.3002
7 Months	.2985	.2968	.2951	.2934	.2917	.2900	.2884	.2867	.2851	.2834
10	.2818	.2802	.2786	.2770	.2754	.2738	.2722	.2707	.2691	.2676
20	.2660	.2645	.2630	.2615	.2600	.2585	.2570	.2555	.2541	.2526
8 Months	.2512	.2497	.2483	.2469	.2454	.2440	.2426	.2412	.2398	.2385

Sodium – 24

14.96 Hours

Hours	Minutes											
	0	10	20	30	40	50	60	70	80	90	100	110
0	1.0000	.9923	.9847	.9771	.9696	.9621	.9547	.9474	.9401	.9329	.9257	.9186
2	.9115	.9045	.8975	.8906	.8838	.8770	.8702	.8635	.8569	.8503	.8438	.8373
4	.8308	.8244	.8181	.8118	.8056	.7994	.7932	.7871	.7811	.7750	.7691	.7632
6	.7573	.7515	.7457	.7400	.7343	.7286	.7230	.7174	.7119	.7065	.7010	.6956
8	.6903	.6850	.6797	.6745	.6693	.6641	.6590	.6540	.6489	.6439	.6390	.6341
10	.6292	.6243	.6195	.6148	.6100	.6054	.6007	.5961	.5915	.5869	.5824	.5779
12	.5735	.5691	.5647	.5604	.5561	.5518	.5475	.5433	.5391	.5350	.5309	.5268
14	.5227	.5187	.5147	.5108	.5068	.5029	.4991	.4952	.4914	.4876	.4839	.4802
16	.4765	.4728	.4692	.4656	.4620	.4584	.4549	.4514	.4479	.4445	.4411	.4377
18	.4343	.4310	.4277	.4244	.4211	.4179	.4146	.4115	.4083	.4051	.4020	.3989
20	.3959	.3928	.3898	.3868	.3838	.3809	.3779	.3750	.3722	.3693	.3665	.3636
22	.3608	.3581	.3553	.3526	.3499	.3472	.3445	.3418	.3392	.3366	.3340	.3314
1 Day	.3289	.3264	.3239	.3214	.3189	.3164	.3140	.3116	.3092	.3068	.3045	.3021
2	.2998	.2975	.2952	.2929	.2907	.2884	.2862	.2840	.2818	.2797	.2775	.2754
4	.2733	.2712	.2691	.2670	.2649	.2629	.2609	.2589	.2569	.2549	.2530	.2510
6	.2491	.2472	.2453	.2434	.2415	.2396	.2378	.2360	.2342	.2324	.2306	.2288
8	.2270	.2253	.2236	.2218	.2201	.2184	.2168	.2151	.2134	.2118	.2102	.2085
10	.2069	.2053	.2038	.2022	.2006	.1991	.1976	.1960	.1945	.1930	.1916	.1901
12	.1886	.1872	.1857	.1843	.1829	.1815	.1801	.1787	.1773	.1760	.1746	.1733
14	.1719	.1706	.1693	.1680	.1667	.1654	.1641	.1629	.1616	.1604	.1592	.1579
16	.1567	.1555	.1543	.1531	.1519	.1508	.1496	.1485	.1473	.1462	.1451	.1440
18	.1428	.1417	.1407	.1396	.1385	.1374	.1364	.1353	.1343	.1333	.1322	.1312
20	.1302	.1292	.1282	.1272	.1262	.1253	.1243	.1234	.1224	.1215	.1205	.1196
22	.1187	.1178	.1169	.1160	.1151	.1142	.1133	.1124	.1116	.1107	.1099	.1090
2 Days	.1082	.1073	.1065	.1057	.1049	.1041	.1033	.1025	.1017	.1009	.1001	.0994

Strontium – 85

64 Days

Days	Days									
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.0000	.9946	.9892	.9839	.9786	.9733	.9680	.9628	.9576	.9524
5	.9473	.9422	.9371	.9320	.9270	.9220	.9170	.9121	.9071	.9022
10	.8974	.8925	.8877	.8829	.8781	.8734	.8687	.8640	.8593	.8547
15	.8501	.8455	.8409	.8364	.8318	.8273	.8229	.8184	.8140	.8096
20	.8052	.8009	.7966	.7923	.7880	.7837	.7795	.7753	.7711	.7669
25	.7628	.7587	.7546	.7505	.7465	.7424	.7384	.7344	.7305	.7265
1 Month	.7226	.7187	.7148	.7109	.7071	.7033	.6995	.6957	.6920	.6882
5	.6845	.6808	.6771	.6735	.6698	.6662	.6626	.6590	.6555	.6519
10	.6484	.6449	.6414	.6380	.6345	.6311	.6277	.6243	.6209	.6176
15	.6142	.6109	.6076	.6043	.6011	.5978	.5946	.5914	.5882	.5850
20	.5819	.5787	.5756	.5725	.5694	.5663	.5633	.5602	.5572	.5542
25	.5512	.5482	.5453	.5423	.5394	.5365	.5336	.5307	.5278	.5250
2 Months	.5221	.5193	.5165	.5137	.5109	.5082	.5054	.5027	.5000	.4973
5	.4946	.4919	.4893	.4866	.4840	.4814	.4788	.4762	.4736	.4711
10	.4685	.4660	.4635	.4610	.4585	.4560	.4536	.4511	.4487	.4463
15	.4438	.4414	.4391	.4367	.4343	.4320	.4297	.4273	.4250	.4227
20	.4204	.4182	.4159	.4137	.4114	.4092	.4070	.4048	.4026	.4004
25	.3983	.3961	.3940	.3919	.3898	.3876	.3856	.3835	.3814	.3793
3 Months	.3773	.3753	.3732	.3712	.3692	3672	.3652	.3633	.3613	.3593
5	.3574	.3555	.3536	.3516	.3497	.3479	.3460	.3441	.3423	.3404
10	.3386	.3367	.3349	.3331	.3313	.3295	.3277	.3260	.3242	.3225
15	.3207	.3190	.3173	.3155	.3138	.3122	.3105	.3088	.3071	.3055
20	.3038	.3022	.3005	.2989	.2973	.2957	.2941	.2925	.2909	.2894
25	.2878	.2862	.2847	.2832	.2816	.2801	.2786	.2771	.2756	.2741
4 Months	.2726	.2712	.2697	.2682	.2668	.2653	.2639	.2625	.2611	.2597

Strontium – 87m

2.83 Hours

Minutes	Minutes									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9959	.9919	.9878	.9838	.9798	.9758	.9718	.9679	.9639
10	.9600	.9561	.9522	.9483	.9445	.9406	.9368	.9330	.9292	.9254
20	.9216	.9178	.9141	.9104	.9067	.9030	.8993	.8956	.8920	.8884
30	.8847	.8811	.8775	.8740	.8704	.8669	.8633	.8598	.8563	.8528
40	.8493	.8459	.8424	.8390	.8356	.8322	.8288	.8254	.8221	.8187
50	.8154	.8121	.8087	.8055	.8022	.7989	.7956	.7924	.7892	.7860
1 Hour	.7828	.7796	.7764	.7732	.7701	.7669	.7638	.7607	.7576	.7545
10	.7515	.7484	.7453	.7423	.7393	.7363	.7333	.7303	.7273	.7243
20	.7214	.7185	.7155	.7126	.7097	.7068	.7039	.7011	.6982	.6954
30	.6925	.6897	.6869	.6841	.6813	.6785	.6758	.6730	.6703	.6676
40	.6648	.6621	.6594	.6567	.6541	.6514	.6488	.6461	.6435	.6409
50	.6382	.6356	.6331	.6305	.6279	.6253	.6228	.6203	.6177	.6152
2 Hours	.6127	.6102	.6077	.6053	.6028	.6003	.5979	.5955	.5930	.5906
10	.5882	.5858	.5834	.5810	.5787	.5763	.5740	.5716	.5693	.5670
20	.5647	.5624	.5601	.5578	.5555	.5533	.5510	.5488	.5465	.5443
30	.5421	.5399	.5377	.5355	.5333	.5311	.5290	.5268	.5247	.5225
40	.5204	.5183	.5162	.5141	.5120	.5099	.5078	.5057	.5037	.5016
50	.4996	.4976	.4955	.4935	.4915	.4895	.4875	.4855	.4835	.4816
3 Hours	.4796	.4777	.4757	.4738	.4718	.4699	.4680	.4661	.4642	.4623
10	.4604	.4585	.4567	.4548	.4530	.4511	.4493	.4475	.4456	.4438
20	.4420	.4402	.4384	.4366	.4348	.4331	.4313	.4296	.4278	.4261
30	.4243	.4226	.4209	.4192	.4175	.4158	.4141	.4124	.4107	.4090
40	.4074	.4057	.4040	.4024	.4008	.3991	.3975	.3959	.3943	.3927
50	.3911	.3895	.3879	.3863	.3847	.3832	.3816	.3800	.3785	.3770
4 Hours	.3754	.3739	.3724	.3708	.3693	.3678	.3663	.3648	.3634	.3619

Sulfur – 35

87.9 Days

Days	Days									
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.0000	.9961	.9921	.9882	.9844	.9805	.9766	.9728	.9689	.9651
5	.9613	.9576	.9538	.9500	.9463	.9426	.9389	.9352	.9315	.9278
10	.9242	.9205	.9169	.9133	.9097	.9061	.9026	.8990	.8955	.8920
15	.8884	.8849	.8815	.8780	.8745	.8711	.8677	.8643	.8609	.8575
20	.8541	.8507	.8474	.8441	.8407	.8374	.8341	.8308	.8276	.8243
25	.8211	.8178	.8146	.8114	.8082	.8050	.8019	.7987	.7956	.7924
1 Month	.7893	.7862	.7831	.7800	.7770	.7739	.7709	.7678	.7648	.7618
5	.7588	.7558	.7529	.7499	.7469	.7440	.7411	.7382	.7353	.7324
10	.7295	.7266	.7237	.7209	.7181	.7152	.7124	.7096	.7068	.7040
15	.7013	.6985	.6958	.6930	.6903	.6876	.6849	.6822	.6795	.6768
20	.6742	.6715	.6689	.6662	.6636	.6610	.6584	.6558	.6532	.6507
25	.6481	.6455	.6430	.6405	.6380	.6354	.6329	.6305	.6280	.6255
2 Months	.6230	.6206	.6182	.6157	.6133	.6109	.6085	.6061	.6037	.6013
5	.5990	.5966	.5943	.5919	.5896	.5873	.5850	.5827	.5804	.5781
10	.5758	.5735	.5713	.5690	.5668	.5646	.5623	.5601	.5579	.5557
15	.5535	.5514	.5492	.5470	.5449	.5427	.5406	.5385	.5364	.5342
20	.5321	.5300	.5280	.5259	.5238	.5218	.5197	.5177	.5156	.5136
25	.5116	.5096	.5075	.5056	.5036	.5016	.4996	.4976	.4957	.4937
3 Months	.4918	.4899	.4879	.4860	.4841	.4822	.4803	.4784	.4765	.4746
5	.4728	.4709	.4691	.4672	.4654	.4635	.4617	.4599	.4581	.4563
10	.4545	.4527	.4509	.4492	.4474	.4456	.4439	.4421	.4404	.4387
15	.4369	.4352	.4335	.4318	.4301	.4284	.4267	.4250	.4234	.4217
20	.4200	.4184	.4167	.4151	.4135	.4118	.4102	.4086	.4070	.4054
25	.4038	.4022	.4006	.3990	.3975	.3959	.3944	.3928	.3913	.3897
4 Months	.3882	.3867	.3851	.3836	.3821	.3806	.3791	.3776	.3761	.3747

Technetium – 99m

6.049 Hours

Minutes	Minutes									
	0	2	4	6	8	10	12	14	16	18
0	1.0000	.9962	.9924	.9885	.9848	.9810	.9772	.9735	.9697	.9660
20	.9623	.9586	.9550	.9513	.9477	.9440	.9404	.9368	.9332	.9296
40	.9261	.9225	.9190	.9155	.9120	.9085	.9050	.9015	.8981	.8946
1 Hour	.8912	.8878	.8844	.8810	.8776	.8743	.8709	.8676	.8642	.8609
20	.8576	.8543	.8511	.8478	.8446	.8413	.8381	.8349	.8317	.8285
40	.8253	.8222	.8190	.8159	.8127	.8096	.8065	.8034	.8004	.7973
2 Hours	.7942	.7912	.7882	.7851	.7821	.7791	.7761	.7732	.7702	.7673
20	.7643	.7614	.7585	.7556	.7527	.7498	.7469	.7440	.7412	.7384
40	.7355	.7327	.7299	.7271	.7243	.7215	.7188	.7160	.7133	.7105
3 Hours	.7078	.7051	.7024	.6997	.6970	.6944	.6917	.6890	.6864	.6838
20	.6812	.6785	.6759	.6734	.6708	.6682	.6656	.6631	.6606	.6580
40	.6555	.6530	.6505	.6480	.6455	.6430	.6406	.6381	.6357	.6332
4 Hours	.6308	.6284	.6260	.6236	.6212	.6188	.6164	.6141	.6117	.6094
20	.6070	.6047	.6024	.6001	.5978	.5955	.5932	.5909	.5887	.5864
40	.5842	.5819	.5797	.5775	.5753	.5731	.5709	.5687	.5665	.5643
5 Hours	.5622	.5600	.5579	.5557	.5536	.5515	.5494	.5473	.5452	.5431
20	.5410	.5389	.5369	.5348	.5328	.5307	.5287	.5267	.5246	.5226
40	.5206	.5186	.5166	.5147	.5127	.5107	.5088	.5068	.5049	.5029
6 Hours	.5010	.4991	.4972	.4953	.4934	.4915	.4896	.4877	.4859	.4840
20	.4821	.4803	.4784	.4766	.4748	.4730	.4712	.4694	.4676	.4658
40	.4640	.4622	.4604	.4587	.4569	.4552	.4534	.4517	.4499	.4482
7 Hours	.4465	.4448	.4431	.4414	.4397	.4380	.4363	.4347	.4330	.4313
20	.4297	.4280	.4264	.4248	.4231	.4215	.4199	.4183	.4167	.4151
40	.4135	.4119	.4103	.4088	.4072	.4056	.4041	.4025	.4010	.3994
8 Hours	.3979	.3964	.3949	.3934	.3919	.3904	.3889	.3874	.3859	.3844

Days	Hours											
	0	1	2	3	4	5	6	7	8	9	10	11
0.0	1.0000	.9945	.9891	.9837	.9783	.9730	.9677	.9624	.9571	.9519	.9467	.9415
0.5	.9364	.9312	.9261	.9211	.9160	.9110	.9061	.9011	.8962	.8913	.8864	.8816
1.0	.8768	.8720	.8672	.8625	.8577	.8531	.8484	.8438	.8391	.8346	.8300	.8255
1.5	.8210	.8165	.8120	.8076	.8032	.7988	.7944	.7901	.7857	.7814	.7772	.7729
2.0	.7687	.7645	.7603	.7562	.7520	.7479	.7438	.7398	.7357	.7317	.7277	.7237
2.5	.7198	.7158	.7119	.7080	.7042	.7003	.6965	.6927	.6889	.6851	.6814	.6777
3.0	.6740	.6703	.6666	.6630	.6593	.6557	.6522	.6486	.6451	.6415	.6380	.6345
3.5	.6311	.6276	.6242	.6208	.6174	.6140	.6107	.6073	.6040	.6007	.5974	.5941
4.0	.5909	.5877	.5845	.5813	.5781	.5749	.5718	.5687	.5656	.5625	.5594	.5563
4.5	.5533	.5503	.5473	.5443	.5413	.5383	.5354	.5325	.5296	.5267	.5238	.5209
5.0	.5181	.5152	.5124	.5096	.5068	.5041	.5013	.4986	.4959	.4931	.4904	.4878
5.5	.4851	.4824	.4798	.4772	.4746	.4720	.4694	.4668	.4643	.4618	.4592	.4567
6.0	.4542	.4517	.4493	.4468	.4444	.4419	.4395	.4371	.4347	.4324	.4300	.4277
6.5	.4253	.4230	.4207	.4184	.4161	.4138	.4116	.4093	.4071	.4048	.4026	.4004
7.0	.3982	.3961	.3939	.3918	.3896	.3875	.3854	.3833	.3812	.3791	.3770	.3749
7.5	.3729	.3709	.3688	.3668	.3648	.3628	.3608	.3589	.3569	.3550	.3530	.3511
8.0	.3492	.3473	.3454	.3435	.3416	.3397	.3379	.3360	.3342	.3324	.3305	.3287
8.5	.3269	.3252	.3234	.3216	.3199	.3181	.3164	.3146	.3129	.3112	.3095	.3078
9.0	.3061	.3045	.3028	.3011	.2995	.2979	.2962	.2946	.2930	.2914	.2898	.2882
9.5	.2866	.2851	.2835	.2820	.2804	.2789	.2774	.2759	.2744	.2729	.2714	.2699
10.0	.2684	.2669	.2655	.2640	.2626	.2611	.2597	.2583	.2569	.2555	.2541	.2527
10.5	.2513	.2499	.2486	.2472	.2459	.2445	.2432	.2419	.2405	.2392	.2379	.2366
11.0	.2353	.2340	.2328	.2315	.2302	.2290	.2277	.2265	.2252	.2240	.2228	.2216
11.5	.2203	.2191	.2179	.2168	.2156	.2144	.2132	.2121	.2109	.2097	.2086	.2075
12.0	.2063	.2052	.2041	.2030	.2018	.2007	.1996	.1986	.1975	.1964	.1953	.1943

Zinc – 65

245 Days

Days	Days									
	0	2	4	6	8	10	12	14	16	18
0	1.0000	.9944	.9887	.9832	.9776	.9721	.9666	.9612	.9557	.9503
20	.9450	.9397	.9344	.9291	.9238	.9186	.9134	.9083	.9032	.8981
40	.8930	.8880	.8830	.8780	.8730	.8681	.8632	.8583	.8535	.8487
60	.8439	.8391	.8344	.8297	.8250	.8203	.8157	.8111	.8065	.8020
80	.7975	.7930	.7885	.7840	.7796	.7752	.7708	.7665	.7622	.7579
100	.7536	.7493	.7451	.7409	.7367	.7326	.7284	.7243	.7202	.7162
120	.7121	.7081	.7041	.7001	.6962	.6923	.6884	.6845	.6806	.6768
140	.6730	.6692	.6654	.6616	.6579	.6542	.6505	.6468	.6432	.6395
160	.6359	.6323	.6288	.6252	.6217	.6182	.6147	.6112	.6078	.6044
180	.6009	.5976	.5942	.5908	.5875	.5842	.5809	.5776	.5743	.5711
200	.5679	.5647	.5615	.5583	.5552	.5520	.5489	.5458	.5428	.5397
220	.5366	.5336	.5306	.5276	.5246	.5217	.5187	.5158	.5129	.5100
240	.5071	.5043	.5014	.4986	.4958	.4930	.4902	.4874	.4847	.4819
260	.4792	.4765	.4738	.4712	.4685	.4659	.4632	.4606	.4580	.4554
280	.4529	.4503	.4478	.4452	.4427	.4402	.4377	.4353	.4328	.4304
300	.4279	.4255	.4231	.4207	.4184	.4160	.4137	.4113	.4090	.4067
320	.4044	.4021	.3999	.3976	.3954	.3931	.3909	.3887	.3865	.3843
340	.3822	.3800	.3779	.3757	.3736	.3715	.3694	.3673	.3652	.3632
360	.3611	.3591	.3571	.3551	.3531	.3511	.3491	.3471	.3452	.3432
380	.3413	.3393	.3374	.3355	.3336	.3317	.3299	.3280	.3262	.3243
400	.3225	.3207	.3189	.3171	.3153	.3135	.3117	.3100	.3082	.3065
420	.3048	.3030	.3013	.2996	.2979	.2963	.2946	.2929	.2913	.2896
440	.2880	.2864	.2847	.2831	.2815	.2800	.2784	.2768	.2752	.2737
460	.2721	.2706	.2691	.2676	.2661	.2646	.2631	.2616	.2601	.2586
480	.2572	.2557	.2543	.2528	.2514	.2500	.2486	.2472	.2458	.2444

U.S. NUCLEAR REGULATORY COMMISSION

November 1975
Revision 1

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 8.13

INSTRUCTION CONCERNING PRENATAL RADIATION EXPOSURE

A. INTRODUCTION

Section 19.12 of 10 CFR Part 19 states that all individuals working in or frequenting any portion of a restricted area must be instructed in the health protection problems associated with exposure to radioactive materials or radiation. This guide describves the instruction that should be provided concerning biological risks to embryos or fetuses resulting from prenatal exposure.*

B. DISCUSSION

Since the Law of Bergonie and Tribondeau was published in 1906** it has been known that the sensitivity of cells to radiation damage is related to their reproductive activity and inversely related to their degree of differentiation. It follows that children could be expected to be more radiosensitive than adults, fetuses more radiosensitive than children, and embryos even more radiosensitive.

This principle has long been a factor in the development of radiation exposure standards. Section 20.104 of 10 CFR Part 20 places different limits on minors than on adult workers. Specifically, it limits anyone under the age of 18 to exposures not exceeding 10% of the limits for adult workers. However, § 20.104 does not relate to embryos or fetuses.

A special situation arises when an occupationally exposed woman is pregnant. Exposure of the abdomen of such a worker to penetrating radiation from either external or internal sources would also involve exposure of the embryo or fetus. Because a number of studies have indicated that the embryo or fetus is more sensitive than an adult, particularly during the first three months after conception, when a woman may not be aware that she is pregnant, the National Council on Radiation Protection and Measurements (NCRP) recommended in its Report No. 39 that special precautions be taken to limit exposure when an occupationally exposed woman could be pregrant.

C. REGULATORY POSITION

Instruction to workers performed under § 19.12 should be given prior to assignment to work in a restricted area. In providing instruction about health protection problems associated with radiation exposure, female workers and those who may supervise or work with them should be given specific instruction about prenatal exposure risks to the developing embryo and fetus.

The instruction should ensure that the employees understand:

1. That the NCRP has recommended that, during the entire gestation period, the maximum permissible dose equivalent to the fetus from occupational exposure of the expectant mother should not exceed 0.5 rem and

2. The reasons for this recommendation.

The instruction should include the information provided in the Appendix to this guide. It should be presented to the employee, her supervisors, and her coworkers both orally and in written form. Each individual should be given an opportunity to ask questions, and each individual should be asked to acknowledge in writing that the instruction has been received.

D. IMPLEMENTATION

The purpose of this section is to provide information to licensees regarding the use of this guide.

*This revision of the guide includes minor changes of a clarifying nature incorporated as a result of public comments. No substantive changes have been made.

**_Comptes Rendus des Seances de l'Academie des Sciences,_ Vol. 143, pp. 983-985, 1906.

USNRC REGULATORY GUIDES

Regulatory Guides are issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience. This guide was revised as a result of substantive comments received from the public and additional staff review.

Comments should be sent to the Secretary of the Commission, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Attention: Docketing and Service Section.

The guides are issued in the following ten broad divisions:

1. Power Reactors
2. Research and Test Reactors
3. Fuels and Materials Facilities
4. Environmental and Siting
5. Materials and Plant Protection
6. Products
7. Transportation
8. Occupational Health
9. Antitrust Review
10. General

Copies of published guides may be obtained by written request indicating the divisions desired to the U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Attention: Director, Office of Standards Development.

Except in those cases in which the licensee chooses to propose an alternative method for complying with the portion of the Commission's regulations previously specified, the methods described herein should be used immediately to instruct female employees working in or frequenting any portion of a restricted area, and those who may supervise or work with such employees, concerning the health protection problems associated with prenatal radiation exposure.

APPENDIX TO REGULATORY GUIDE 8.13

POSSIBLE HEALTH RISKS TO CHILDREN OF WOMEN WHO ARE EXPOSED TO RADIATION DURING PREGNANCY

Some recent studies have shown that the risk of leukemia and other cancers in children increases if the mother is exposed to a significant amount of radiation during pregnancy. According to a report by the National Academy of Sciences, the incidence of leukemia among children from birth to 10 years of age in the United States could rise from 3.7 cases in 10,000 children to 5.6 cases in 10,000 children if the children were exposed to 1 rem of radiation before birth (a "rem" is a measure of radiation). The Academy has also estimated that an equal number of other types of cancers could result from this level of radiation. Although other scientific studies have shown a much smaller effect from radiation, the Nuclear Regulatory Commission wants women employees of its licensees to be aware of any possible risk so that the women can take steps they think appropriate to protect their offspring.

As an employee of a Nuclear Regulatory Commission licensee, you may be exposed to more radiation than the general public. However, the Nuclear Regulatory Commission has established a basic exposure limit for all occupationally exposed adults of 1.25 rems per calendar quarter, or 5 rems per year. No clinical evidence of harm would be expected in an adult working within these levels for a lifetime. Because the risks of undesirable effects may be greater for young people individuals under 18 years of age are permitted to be exposed to only 10 percent of the adult occupational limits. (This lower limit is also applied to members of the general public.)

The scientific organization called the National Council on Radiation Protection and Measurements has recommended that because unborn babies may be more sensitive to radiation than adults, their radiation dose as a result of occupational exposure of the mother should not exceed 0.5 rem. Other scientific groups, including the International Commission on Radiation Protection, have also stressed the need to keep radiation doses to unborn children as low as is reasonably achievable.

All Nuclear Regulatory Commission licensees are now required* to inform all individuals who work in a restricted area of the health protection problems associated with radiation exposure. This instruction would in many cases include information on the possible risks to unborn babies. The regulations also state** that licensees should keep radiation exposures as low as is reasonably achievable. According to the National Council on Radiation Protection and Measurements, vigorous efforts should be made to keep the radiation exposure of an embryo or fetus at the very lowest practicable level during the entire period of pregnancy.

Thus it is the responsibility of your employer to take all practicable steps to reduce your radiation exposure. Then it is your responsibility to decide whether the exposure you are receiving is sufficiently low to protect your unborn child. The advice of your employer's health physicist or radiation protection officer should be obtained to determine whether radiation levels in your working areas are high enough that a baby could receive 0.5 rem or more before birth. If so, the alternatives that you might want to consider are:

(a) If you are now pregnant or expect to be soon, you could decide not to accept or continue assignments in these areas.

(b) You could reduce your exposure, where possible, by decreasing the amount of time you spend in the radiation area, increasing your distance from the radiation source, and using shielding.

(c) If you do become pregnant, you could ask your employer to reassign you to areas involving less exposure to radiation. If this is not possible, you might consider leaving your job. If you decide to take such steps, do so without delay. The unborn child is most

*By Title 10, Part 19 of the Code of Federal Regulations.
**In Title 10, Part 20.

sensitive to radiation during the first three months of your pregnancy.

(d) You could delay having children until you are no longer working in an area where the radiation dose to your unborn baby could exceed 0.5 rem.

You may also, of course, choose to:

(e) Continue working in the higher radiation areas, but with full awareness that you are doing so at some small increased risk for your unborn child.

The following facts should be noted to help you make a decision:

1. The first three months of pregnancy are the most important, so you should make your decision quickly.

2. In most cases of occupational exposure, the actual dose received by the unborn baby is less than the dose received by the mother because some of the dose is absorbed by the mother's body.

3. At the present occupational exposure limit, the actual risk to the unborn baby is small, but experts disagree on the exact amount of risk.

4. There is no need to be concerned about sterility or loss of your ability to bear children. The radiation dose required to produce such effects is more than 100 times larger than the Nuclear Regulatory Commission's dose limits for adults.

5. Even if you work in an area where you receive only 0.5 rem per three-month period, in nine months you could receive 1.5 rems, and the unborn baby could receive more than 0.5 rem, the full-term limit suggested by the NCRP. Therefore, if you decide to restrict your unborn baby's exposure as recommended by the NCRP, be aware that the 0.5 rem limit to the unborn baby applies to the full nine-month pregnancy.

The remainder of this document contains a brief explanation of radiation and its effects on humans. As you will see, some radiation is present everywhere and the levels of radiation most employees of Nuclear Regulatory Commission licensees receive are not much larger than these natural levels. Because the radiation levels in the facility where you will be working are required by law to be kept quite low, there is not considered to be a significant health risk to individual adult employees.

Discussion of Radiation

The amount of radiation an individual receives is called the "dose" and is measured in "rems." The average individual in the United States accumulates a dose of one rem from natural sources every 12 years. The dose from natural radiation is higher in some states, such as Colorado, Wyoming, and South Dakota, primarily because of cosmic radiation. There the average individual gets one rem every 8 years.

Natural background radiation levels are also much higher in certain local areas. A dose of one rem may be received in some areas on the beach at Guarapari, Brazil, in only about 9 days, and some people in Kerala, India, get a dose of one rem every 5 months.

Many people receive additional radiation for medical reasons. In 1970, an estimated 212 million X-ray examinations were performed in the United States. The estimated average surface skin dose from one radiographic chest X-ray is 0.027 rem. The estimated average surface skin dose per abdominal X-ray is 0.62 rem.*

Radiation can also be received from natural sources such as rock or brick structures, from consumer products such as television and glow-in-the-dark watches, and from air travel. The possible annual dose from working 8 hours a day near a granite wall at the Redcap stand in Grand Central Station, New York City, is 0.2 rem, and the average annual dose in the United States from TV, consumer products, and air travel is 0.0026 rem.

Radiation, like many things, can be harmful. A large dose to the whole body (such as 600 rems in one day) would probably cause death in about 30 days, but such large doses result only from rare accidents. Control of exposure to radiation is based on the assumption that any exposure, no matter how small, involves some risk. The occupational exposure limits are set so low, however, that medical evidence gathered over the past 50 years indicates no clinically observable injuries to individuals due to radiation exposures when the established radiation limits are not exceeded. This was true even for exposures received under the early occupational exposure limits, which were many times higher than the present limits. Thus the risk to individuals at the occupational exposure levels is considered to be very low. However, it is impossible to say that the risk is zero. To decrease the risk still further, licensees are expected to keep actual exposures as far below the limits as is reasonably achievable.

*"Pre-Release Report: X-Ray Exposure Study (XES) Revised Estimates of 1964 and 1970 Genetically Significant Dose," February 4, 1975, U.S. Department of Health, Education, and Welfare, Public Health Service, Federal Drug Administration, Bureau of Radiological Health.

The current exposure limits for people working with radiation have been developed and carefully reviewed by nationally and internationally recognized groups of scientists. It must be remembered, however, that these limits are for adults. Special consideration is appropriate when the individual being exposed is, or may be, an expectant mother, because the exposure of an unborn child may also be involved.

Prenatal Irradiation

The prediction that an unborn child would be more sensitive to radiation than an adult is supported by observations for relatively large doses. Large doses delivered before birth alter both physical development and behavior in experimentally exposed animals. A report of the National Academy of Sciences states that short-term doses in the range of 10 to 20 rems cause subtle changes in the nerve cells of unborn and infant rats. The report also states, however, that no radiation induced changes in development have been demonstrated to result in experimental animals from doses up to about 1 rem per day extended over a large part of the period before birth.

The National Academy of Sciences also noted that doses of 25 to 50 rems to a pregnant human may cause growth disturbances in her offspring. Such doses substantially exceed, of course, the maximum permissible occupational exposure limits.

Concern about prenatal exposure (i.e., exposure of a child while in its mother's uterus) at the permissible occupational levels is primarily based on the possibility that cancer (especially leukemia) may develop during the first 10 years of the child's life. Several studies have been performed to evaluate this risk. One study involved the followup of 77,000 children exposed to radiation before birth (because of diagnostic abdominal X-rays made for medical purposes during their mother's pregnancy). Another study involved the followup of 20,000 such children. In addition, 1292 children who received prenatal exposure during the bombing of Hiroshima and Nagasaki were studied. Although contradictory results have been obtained, most of the evidence suggests a relationship between prenatal exposure and an increased risk of childhood cancer.

Summary

Occupational exposures to radiation are being kept low. However, qualified scientists have recommended that the radiation dose to an embryo or fetus as a result of occupational exposure of the expectant mother should not exceed 0.5 rem because of possible increased risk of childhood leukemia and cancer. Since this 0.5 rem is lower than the dose generally permitted to adult workers, women may want to take special actions to avoid receiving higher exposures, just as they might stop smoking during pregnancy or might climb stairs more carefully to reduce possible risks to their unborn children.

Bibliography

1. Donald G. Pizzarello and Richard L. Witcofski, *Basic Radiation Biology,* Philadelphia: Lea and Febizer, 1967.

2. National Academy of Sciences — National Research Council, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation,* Washington, D.C., November 1972.

3. National Council on Radiation Protection and Measurements, *Basic Radiation Protection Criteria,* NRCP Report No. 39, Washington, D.C., January 15, 1971.

4. United Nations, *Ionizing Radiation: Levels and Effects,* 2 vol., Reports of the United Nations Scientific Committee on the Effects of Atomic Radiation, Report No. A/8725, United Nations, New York, 1972.

5. U.S. Atomic Energy Commission, Division of Technical Information, Understanding the Atom Series:

   Atoms, Nature and Man

   The Genetic Effects of Radiation

   The Natural Radiation Environment

   Your Body and Radiation

Reproduced at the National Institutes of Health, Bethesda, Maryland
(Page numbers changed from those on original.)

PART 19

NOTICES, INSTRUCTIONS, AND REPORTS TO WORKERS; INSPECTIONS

Sec.

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AUTHORITY: Secs. 53, 63, 81, 103, 104, 161, Pub. L. 83–703, 68 Stat. 930, 933, 935, 936, 937, 948, as amended (42 U.S.C. 2073, 2093, 2111, 2133, 2134, 2201); Sec. 401, Pub. L. 93–438, 88 stat. 1254 (42 U.S.C. 5891)

40 FR 8774

§ 19.1 Purpose.

The regulations in this part establish requirements for notices, instructions, and reports by licensees to individuals participating in licensed activities, and options available to such individuals in connection with Commission inspections of licensees to ascertain compliance with the provisions of the Atomic Energy Act of 1954, as amended, Title II of the Energy Reorganization Act of 1974, and regulations, orders, and licenses thereunder regarding radiological working conditions.

40 FR 8774

§ 19.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed by the Nuclear Regulatory Commission pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

38 FR 22217

§ 19.3 Definitions.

As used in this part:

(a) "Act" means the Atomic Energy Act of 1954, (68 Stat. 919) including any amendments thereto;

(b) "Commission" means the United States Nuclear Regulatory Commission;

(c) "Worker" means an individual engaged in activities licensed by the Commission and controlled by a licensee, but does not include the licensee.

(d) "License" means a license issued under the regulations in Parts 30 through 35, 40, or 70 of this chapter, including licenses to operate a production or utilization facility pursuant to Part 50 of this chapter. "Licensee" means the holder of such a license.

38 FR 22217

(e) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

§ 19.4 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

40 FR 8774

§ 19.5 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street, NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

38 FR 22217

§ 19.11 Posting of notices to workers.

(a) Each licensee shall post current copies of the following documents: (1) The regulations in this part and in Part 20 of this chapter; (2) the license, license conditions, or documents incorporated into a license by reference, and amendments thereto; (3) the operating procedures applicable to licensed activities; (4) any notice of violation involving radiological working conditions, proposed imposition of civil penalty, or order issued pursuant to Subpart B of Part 2 of this chapter, and any response from the licensee.

38 FR 22217

(b) If posting of a document specified in paragraph (a) (1), (2) or (3) of this section is not practicable, the licensee may post a notice which describes the document and states where it may be examined.

40 FR 8774

(c) Form NRC–3, "Notice to Employees", shall be posted by each licensee wherever individuals work in or frequent any portion of a restricted area.

NOTE: Copies of Form NRC–3 may be obtained by writing to the Director of the appropriate U.S. Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix "D", Part 20 of this chapter, or the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

(d) Documents, notices, or forms posted pursuant to this section shall appear in a sufficient number of places to permit individuals engaged in licensed activities to observe them on the way to or from any particular licensed activity location to which the document applies, shall be conspicuous, and shall be replaced if defaced or altered.

(e) Commission documents posted pursuant to paragraph (a)(4) of this section shall be posted within 2 working days after receipt of the documents from the Commission; the licensee's response, if any, shall be posted within 2 working days after dispatch by the licensee. Such documents shall remain posted for a minimum of 5 working days or until action correcting the violation has been completed, whichever is later.

38 FR 22217

§ 19.12 Instructions to workers.

All individuals working in or frequenting any portion of a restricted area shall be kept informed of the storage, transfer, or use of radioactive materials or of radiation in such portions of the restricted area; shall be instructed in the health protection problems associated with exposure to such radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed; shall be instructed in, and instructed to observe, to the extent within the worker's control, the applicable provisions of Commission regulations

and licenses for the protection of personnel from exposures to radiation or radioactive materials occurring in such areas; shall be instructed of their responsibility to report promptly to the licensee any condition which may lead to or cause a violation of Commission regulations and licenses or unnecessary exposure to radiation or to radioactive material; shall be instructed in the appropriate response to warnings made in the event of any unusual occurrence or malfunction that may involve exposure to radiation or radioactive material; and shall be advised as to the radiation exposure reports which workers may request pursuant to § 19.13. The extent of these instructions shall be commensurate with potential radiological health protection problems in the restricted area.

§ 19.13 Notifications and reports to individuals.

(a) Radiation exposure data for an individual, and the results of any measurements, analyses, and calculations of radioactive material deposited or retained in the body of an individual, shall be reported to the individual as specified in this section. The information reported shall include data and results obtained pursuant to Commission regulations, orders or license conditions, as shown in records maintained by the licensee pursuant to Commission regulations. Each notification and report shall: be in writing; include appropriate identifying data such as the name of the licensee, the name of the individual, the individual's social security number; include the individual's exposure information; and contain the following statement:

38 FR 22217

This report is furnished to you under the provisions of the Nuclear Regulatory Commission regulation 10 CFR Part 19. You should preserve this report for further reference.

(b) At the request of any worker, each licensee shall advise such worker annually of the worker's exposure to radiation or radioactive material as shown in records maintained by the licensee pursuant to § 20.401(a) and (c).

(c) At the request of a worker formerly engaged in licensed activities controlled by the licensee, each licensee shall furnish to the worker a report of the worker's exposure to radiation or radioactive material. Such report shall be furnished within 30 days from the time the request is made, or within 30 days after the exposure of the individual has been determined by the licensee, whichever is later; shall cover, within the period of time specified in the request, each calendar quarter in which the worker's activities involved exposure to radiation from radioactive materials licensed by the Commission; and shall include the dates and locations of licensed activities in which the worker participated during this period.

(d) When a licensee is required pursuant to § 20.405 or § 20.408 of this chapter to report to the Commission any exposure of an individual to radiation or radioactive material the licensee shall also provide the individual a report on his exposure data included therein. Such report shall be transmitted at a time not later than the transmittal to the Commission.

§ 19.14 Presence of representatives of licensees and workers during inspections.

(a) Each licensee shall afford to the Commission at all reasonable times opportunity to inspect materials, activities, facilities, premises, and records pursuant to the regulations in this chapter.

(b) During an inspection, Commission inspectors may consult privately with workers as specified in § 19.15. The licensee or licensee's representative may accompany Commission inspectors during other phases of an inspection.

(c) If, at the time of inspection, an individual has been authorized by the workers to represent them during Commission inspections, the licensee shall notify the inspectors of such authorization and shall give the workers' representative an opportunity to accompany the inspectors during the inspection of physical working conditions.

(d) Each workers' representative shall be routinely engaged in licensed activities under control of the licensee and shall have received instructions as specified in § 19.12.

(e) Different representatives of licensees and workers may accompany the inspectors during different phases of an inspection if there is no resulting interference with the conduct of the inspection. However, only one workers' representative at a time may accompany the inspectors.

(f) With the approval of the licensee and the workers' representative an individual who is not routinely engaged in licensed activities under control of the license, for example, a consultant to the licensee or to the workers' representative, shall be afforded the opportunity to accompany Commission inspectors during the inspection of physical working conditions.

(g) Notwithstanding the other provisions of this section, Commission inspectors are authorized to refuse to permit accompaniment by any individual who deliberately interferes with a fair and orderly inspection. With regard to areas containing information classified by an agency of the U.S. Government in the interest of national security, an individual who accompanies an inspector may have access to such information only if authorized to do so. With regard to any area containing proprietary information, the workers' representative for that area shall be an individual previously authorized by the licensee to enter that area.

§ 19.15 Consultation with workers during inspections.

(a) Commission inspectors may consult privately with workers concerning matters of occupational radiation protection and other matters related to applicable provisions of Commission regulations and licenses to the extent the inspectors deem necessary for the conduct of an effective and thorough inspection.

(b) During the course of an inspection any worker may bring privately to the attention of the inspectors, either orally or in writing, any past or present condition which he has reason to believe may have contributed to or caused any violation of the act, the regulations in this chapter, or license condition, or any unnecessary exposure of an individual to radiation from licensed radioactive material under the licensee's control. Any such notice in writing shall comply with the requirements of § 19.16(a).

(c) The provisions of paragraph (b) of this section shall not be interpreted as authorization to disregard instructions pursuant to § 19.12.

§ 19.16 Requests by workers for inspections.

(a) Any worker or representative of workers who believes that a violation of the Act, the regulations in this chapter, or license conditions exists or has occurred in license activities with regard to radiological working conditions in which the worker is engaged, may request an inspection by giving notice of the alleged violation to the Director of Inspection and Enforcement, to the Director of the appropriate Commission Regional Office, or to Commission inspectors. Any such notice shall be in writing, shall set forth the specific grounds for the notice, and shall be signed by the worker or representative of workers. A copy shall be provided the licensee by the Director of Inspection and Enforcement, Regional Office Director, or the inspector no later than at the time of inspection except that, upon the request of the worker giving such notice, his name and the name of individuals referred to therein shall not appear in such copy or on any record published, released, or made available by the Commission, except for good cause shown.

(b) If, upon receipt of such notice, the Director of Inspection and Enforcement or Regional Office Director determines that the complaint meets the requirements set forth in paragraph (a) of this section, and that there are reasonable grounds to believe that the alleged violation exists or has occurred, he shall cause an inspection to be made as soon as practicable, to determine if such alleged violation exists or has occurred. Inspections pursuant to this section need not be limited to matters referred to in the complaint.

(c) No licensee shall discharge or in any manner discriminate against any worker because such worker has filed any complaint or instituted or caused to be instituted any proceeding under the regulations in this chapter or has testified or is about to testify in any such proceeding or because of the exercise by such worker on behalf of himself or others of any option afforded by this part.

§ 19.17 Inspections not warranted; informal review.

(a) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines, with respect to a complaint under § 19.16, that an inspection is not warranted because there are no reasonable grounds to believe that a violation exists or has occurred, he shall notify the complainant in writing of such determination. The complainant may obtain review of such determination by submitting a written statement of posi-

tion with the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, who will provide the licensee with a copy of such statement by certified mail, excluding, at the request of the complainant, the name of the complainant. The licensee may submit an opposing written statement of position with the Executive Director for Operations who will provide the complainant with a copy of such statement by certified mail. Upon the request of the complainant, the Executive Director for Operations or his designee may hold an informal conference in which the complainant and the licensee may orally present their views. An informal conference may also be held at the request of the licensee, but disclosure of the identity of the complainant will be made only following receipt of written authorization from the complainant. After considering all written and oral views presented, the Executive Director for Operations shall affirm, modify, or reverse the determination of the Director of Inspection and Enforcement or of the appropriate Regional Office and furnish the complainant and the licensee a written notification of his decision and the reason therefor.

(b) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines that an inspection is not warranted because the requirements of § 19.16(a) have not been met, he shall notify the complainant in writing of such determination. Such determination shall be without prejudice to the filing of a new complaint meeting the requirements of § 19.16(a).

38 FR 22217

§ 19.30 Violations.

40 FR 8774

An injunction or other court order may be obtained prohibiting any violation of any provision of the Act or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder.

38 FR 22217

A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act or any rule, regulation, or order issued thereunder, or any term, condition or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

§ 19.31 Application for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 19.32 Discrimination prohibited.

No person shall on the ground of sex be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity licensed by the Nuclear Regulatory Commission. This provision will be enforced through agency provisions and rules similar to those already established, with respect to racial and other discrimination, under title VI of the Civil Rights Act of 1964. This remedy is not exclusive, however, and will not prejudice or cut off any other legal remedies available to a discriminatee.

40 FR 8774

PART 20

STANDARDS FOR PROTECTION AGAINST RADIATION

GENERAL PROVISIONS

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AUTHORITY: The provisions of this Part 20 issued under secs. 53, 63, 65, 81, 103, 104, 161, 68 Stat. 930, 933, 935, 936, 937, 948, as amended; 42 U.S.C. 2073, 2093, 2095, 2111, 2133, 2134, 2201. For the purposes of sec. 223, 68 Stat. 958, as amended; 42 U.S.C. 2273, §§20.401-20.409, issued under sec. 161 o., 68 Stat. 950, as amended; 42 U.S.C. 2201 (o). Secs. 202, 206, Pub. L. 93-438, 88 Stat. 1244, 1246 (42 U.S.C. 5842, 5846).

§ 20.1 Purpose.

(a) The regulations in this part establish standards for protection against radiation hazards arising out of activities under licenses issued by the Nuclear Regulatory Commission and are issued pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974. [40 FR 8774]

(b) The use of radioactive material or other sources of radiation not licensed by the Commission is not subject to the regulations in this part. However, it is the purpose of the regulations in this part to control the possession, use, and transfer of licensed material by any licensee in such a manner that exposure to such material and to radiation from such material, when added to exposures to unlicensed radioactive material and to other unlicensed sources of radiation in the possession of the licensee, and to radiation therefrom, does not exceed the standards of radiation protection prescribed in the regulations in this part. [25 FR 10914]

(c) In accordance with recommendations of the Federal Radiation Council, approved by the President, persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as low as is reasonably achievable. The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest. [40 FR 58847]

§ 20.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter. [40 FR 8774]

§ 20.3 Definitions.

(a) As used in this part:

(1) "Act" means the Atomic Energy Act of 1954 (68 Stat. 919) including any amendments thereto;

(2) "Airborne radioactive material" means any radioactive material dispersed in the air in the form of dusts, fumes, mists, vapors, or gases;

(3) "Byproduct material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

(4) "Calendar quarter" means not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year shall begin in January and subsequent calendar quarters shall be such that no day is included in more than one calendar quarter or omitted from inclusion within a calendar quarter. No licensee shall change the method observed by him of determining calendar quarters except at the beginning of a calendar year. [40 FR 42557]

(5) "Commission" means the Nuclear Regulatory Commission or its duly authorized representatives;

(6) "Government agency" means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

(7) "Individual" means any human being;

(8) "Licensed material" means source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or specific license issued by the Commission pursuant to the regulations in this chapter;

(9) "License" means a license issued under the regulations in Part 30, 40, or 70 of this chapter. "Licensee" means the holder of such license;

(10) "Occupational dose" includes exposure of an individual to radiation (i) in a restricted area; or (ii) in the course of employment in which the individual's duties involve exposure to radiation; provided, that "occupational dose" shall not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual.

(11) "Person" means (i) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission or the Administration (except that the Administration shall be considered a person within the meaning of the regulations in this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244)), any State, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (ii) any legal successor, representative, agent, or agency of the foregoing.

(12) "Radiation" means any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves, or visible, infrared, or ultraviolet light;

(13) "Radioactive material" includes any such material whether or not subject to licensing control by the Commission;

(14) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area;

(15) "Source material" means (i) uranium or thorium, or any combination thereof, in any physical or chemical form; or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of *a.* uranium, *b.* thorium or *c.* any combination thereof. Source material does not include special nuclear material.

(16) "Special nuclear material" means (i) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (ii) any material artificially enriched by any of the foregoing but does not include source material;

(17) "Unrestricted area" means any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

(18) "Administration[1]" means the Energy Research and Development Administration or its duly authorized representatives.

(b) Definitions of certain other words and phrases as used in this part are set forth in other sections, including:

(1) "Airborne radioactivity area" defined in § 20.203;

(2) "Radiation area" and "high radiation area" defined in § 20.202;

(3) "Personnel monitoring equipment" defined in § 20.202;

(4) "Survey" defined in § 20.201;

(5) Units of measurement of dose (rad, rem) defined in § 20.4;

(6) Units of measurement of radioactivity defined in § 20.5.

§ 20.4 Units of radiation dose.

(a) "Dose," as used in this part, is the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When the regulations in this part specify a dose during a period of time, the dose means the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units as used in this part are set forth in paragraphs (b) and (c) of this section.

(b) The rad, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue. (One millirad (mrad) = 0.001 rad.)

(c) The rem, as used in this part, is a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem) = 0.001 rem.) The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions of irradiation. For the purpose of the regulations in this part, any of the following is considered to be equivalent to a dose of one rem:

(1) A dose of 1 r due to X— or gamma radiation;

(2) A dose of 1 rad due to X—, gamma, or beta radiation;

(3) A dose of 0.1 rad due to neutrons or high energy protons;

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye;

If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in subparagraph (3) of this paragraph, one rem of neutron radiation may, for purposes of the regulations in this part, be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there exists sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to one rem may be estimated from the following table:

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm²)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm² per sec.)
Thermal	970×10^6	670
0.0001	720×10^6	500
0.005	820×10^6	570
0.02	400×10^6	280
0.1	120×10^6	80
0.5	43×10^6	30
1.0	26×10^6	18
2.5	29×10^6	20
5.0	26×10^6	18
7.5	24×10^6	17
10	24×10^6	17
10 to 30	14×10^6	10

(d) For determining exposures to X or gamma rays up to 3 Mev, the dose limits specified in §§ 20.101 to 20.104, inclusive, may be assumed to be equivalent to the "air dose". For the purpose of this part "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of highest dosage rate.

§ 20.5 Units of radioactivity.

(a) Radioactivity is commonly, and for purposes of the regulations in this part shall be, measured in terms of disintegrations per unit time or in curies. One curie = 3.7×10^{10} disintegrations per second (dps) = 2.2×10^{12} disintegrations per minute (dpm). Commonly used submultiples of the curie are the millicurie and the microcurie:

(1) One millicurie (mCi) [1] = 0.001 curie (Ci) [1] = 3.7×10^7 dps.

(2) One microcurie (μCi) [1] = 0.000001 curie = 3.7×10^4 dps.

[1] Wherever possible, the appropriate unit should be written out as "curie(s)," "millicurie(s)," or "microcurie(s)," and the abbreviations should not be used.

25 FR 10914; 40 FR 8774; 25 FR 10914; 25 FR 13952; 27 FR 5905; 25 FR 10914; 25 FR 13952; 40 FR 8774; 25 FR 10914; 25 FR 10914; 38 FR 29314

(b) [Deleted 40 FR 50704.]

(c) [Deleted 39 FR 23990.]

25 FR 10914

§ 20.6 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

40 FR 8774

§ 20.7 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

25 FR 10914

** Permissible Doses, Levels, and Concentrations

§ 20.101 Exposure of individuals to radiation in restricted areas.

(a) Except as provided in paragraph (b) of this section, no licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of the limits specified in the following table:

Rems per calendar quarter	
1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1¼
2. Hands and forearms; feet and ankles	18¾
3. Skin of whole body	7½

(b) A licensee may permit an individual in a restricted area to receive a dose to the whole body greater than that permitted under paragraph (a) of this section, provided:

(1) During any calendar quarter the dose to the whole body from radioactive material and other sources of radiation in the licensee's possession shall not exceed 3 rems; and

(2) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N–18) rems where "N" equals the individual's age in years at his last birthday; and

(3) The licensee has determined the individual's accumulated occupational dose to the whole body on Form NRC-4, or on a clear and legible record containing all the information required in that form; and has otherwise complied with the requirements of § 20.102. As used in paragraph (b), "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye.

25 FR 10914

§ 20.102 Determination of accumulated dose.

(a) This section contains requirements which must be satisfied by licensees who propose, pursuant to paragraph (b) of § 20.101, to permit individuals in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101.

(b) Before permitting any individual in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101, each licensee shall:

(1) Obtain a certificate on Form NRC-4, or on a clear and legible record containing all the information required in that form, signed by the individual showing each period of time after the individual attained the age of 18 in which the individual received an occupational dose of radiation; and

(2) Calculate on Form NRC-4 in accordance with the instructions appearing therein, or on a clear and legible record containing all the information required in that form, the previously accumulated occupational dose received by the individual and the additional dose allowed for that individual under § 20.101(b).

(c)(1) In the preparation of Form NRC-4, or a clear and legible record containing all the information required in that form, the licensee shall make a reasonable effort to obtain reports of the individual's previously accumulated occupational dose. For each period for which the licensee obtains such reports, the licensee shall use the dose shown in the report in preparing the form. In any case where a licensee is unable to obtain reports of the individual's occupational dose for a previous complete calendar quarter, it shall be assumed that the individual has received the occupational dose specified in whichever of the following columns apply:

25 FR 10914 — 41 FR 18300

Part of body	Column 1 Assumed exposure in rems for calendar quarters prior to Jan. 1, 1961	Column 2 Assumed exposure in rems for calendar quarters beginning on or after Jan. 1, 1961
Whole body, gonads, active blood-forming organs, head and trunk, lens of eye.	3¾	1¼

(2) The licensee shall retain and preserve records used in preparing Form NRC–4 until the Commission authorizes their disposition.

25 FR 10914

If calculation of the individual's accumulated occupational dose for all periods prior to January 1, 1961 yields a result higher than the applicable accumulated dose value for the individual as of that date, as specified in paragraph (b) of § 20.101, the excess may be disregarded.

41 FR 52300

§ 20.103 Exposure of individuals to concentrations of radioactive materials in air in restricted areas.

(a)(1) No licensee shall possess, use, or transfer licensed material in such a manner as to permit any individual in a restricted area to inhale a quantity of radioactive material in any period of one calendar quarter greater than the quantity which would result from inhalation for 40 hours per week for 13 weeks at uniform concentrations of radioactive material in air specified in Appendix B, Table I, Column 1.[1][2][3] If the radioactive material is of such form that intake by absorption through the skin is likely, individual exposures to radioactive material shall be controlled so that the uptake of radioactive material by any organ from either inhalation or absorption or both routes of intake[4][5] in any calendar quarter does not exceed that which would result from inhaling such radioactive material for 40 hours per week for 13 weeks at uniform concentrations specified in Appendix B, Table I, Column 1.

(2) No licensee shall possess, use, or transfer mixtures of U–234, U–235, and

[1] Since the concentration specified for tritium oxide vapor assumes equal intakes by skin absorption and inhalation, the total intake permitted is twice that which would result from inhalation alone at the concentration specified for H 3 S in Appendix B, Table I, Column 1 for 40 hours per week for 13 weeks.

[2] For radioactive materials designated "Sub" in the "Isotope" Column of the table, the concentration value specified is based upon exposure to the material as an external radiation source. Individual exposures to these materials may be accounted for as part of the limitation on individual dose in § 20.101. These materials shall be subject to the precautionary procedures required by § 20.103(b)(1).

[3] Multiply* the concentration values specified in Appendix B, Table I, column 1 by 6.3×10^8 ml to obtain the quarterly quantity limit.

Footnotes 4 and 5 on page 20-4.

*Amended 42 FR 20138.

** Amended 36 FR 1466.

U–238 in soluble form in such a manner as to permit any individual in a restricted area to inhale a quantity of such material in excess of the intake limits specified in Appendix B, Table I, Column 1 of this part. If such soluble uranium is of a form such that absorption through the skin is likely, individual exposures to such material shall be controlled so that the uptake of such material by any organ from either inhalation or absorption or both routes of intake [4] does not exceed that which would result from inhaling such material at the limits specified in Appendix B, Table I, Column 1 and footnote 4 thereto.

(3) For purposes of determining compliance with the requirements of this section the licensee shall use suitable measurements of concentrations of radioactive materials in air for detecting and evaluating airborne radioactivity in restricted areas and in addition, as appropriate, shall use measurements of radioactivity in the body, measurements of radioactivity excreted from the body, or any combination of such measurements as may be necessary for timely detection and assessment of individual intakes of radioactivity by exposed individuals. It is assumed that an individual inhales radioactive material at the airborne concentration in which he is present unless he uses respiratory protective equipment pursuant to paragraph (c) of this section. When assessment of a particular individual's intake of radioactive material is necessary, intakes less than those which would result from inhalation for 2 hours in any one day or for 10 hours in any one week at uniform concentrations specified in Appendix B, Table I, Column 1 need not be included in such assessment, provided that for any assessment in excess of these amounts the entire amount is included.

(b)(1) The licensee shall, as a precautionary procedure, use process or other engineering controls, to the extent practicable, to limit concentrations of radioactive materials in air to levels below those which delimit an airborne radioactivity area as defined in § 20.203(d)(1)(ii).

(2) When it is impracticable to apply process or other engineering controls to limit concentrations of radioactive material in air below those defined in § 20.203(d)(1)(ii), other precautionary procedures, such as increased surveillance, limitation of working times, or provision of respiratory protective equipment, shall be used to maintain intake of radioactive material by any individual within any period of seven consecutive days as far below that intake of radioactive material which would result from inhalation of such material for 40 hours at the uniform concentrations specified in Appendix B, Table 1, Column 1 as is reasonably achievable. Whenever the intake of radioactive material by any individual exceeds this 40-hour control measure, the licensee shall make such evaluations and take such actions as are necessary to assure against recurrence. The licensee shall maintain records of such occurrences, evaluations, and actions taken in a clear and readily identifiable form suitable for summary review and evaluation.

(c) When respiratory protective equipment is used to limit the inhalation of airborne radioactive material pursuant to paragraph (b)(2) of this section, the licensee may make allowance for such use in estimating exposures of individuals to such materials provided that such equipment is used as stipulated in Regulatory Guide 8.15, "Acceptable Programs for Respiratory Protection." [5]

(d) Notwithstanding the provisions of paragraphs (b) and (c) of this section, the Commission may impose further restrictions:

(1) On the extent to which a licensee may make allowance for use of respirators in lieu of provision of process, containment, ventilation, or other engineering controls, if application of such controls is found to be practicable; and

(2) As might be necessary to assure that the respiratory protective program of the licensee is adequate in limiting exposures of personnel to airborne radioactive materials.

(e) The licensee shall notify, in writing, the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D at least 30 days before the date that respiratory protective equipment is first used under the provisions of this section.

(f) A licensee who was authorized to make allowance for use of respiratory protective equipment prior to December 29, 1976 shall bring his respiratory protective program into conformance with the requirements of paragraph (c) of this section within one year of that date, and is exempt from the requirement of paragraph (e) of this section.

[4] Significant intake by ingestion or injection is presumed to occur only as a result of circumstances such as accident, inadvertence, poor procedure, or similar special conditions. Such intakes must be evaluated and accounted for by techniques and procedures as may be appropriate to the circumstances of the occurrence. Exposures so evaluated shall be included in determining whether the limitation on individual exposures in § 20.103(a)(1) has been exceeded.

[5] Regulatory guidance on assessment of individual intakes of radioactive material is given in Regulatory Guide 8.9, "Acceptable Concepts, Models, Equations and Assumptions for a Bioassay Program," single copies of which are available from the Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, upon written request.

[6] This incorporation by reference provision was approved by the Director of the Federal Register on October 19, 1976. Single copies of Regulatory Guide 8.15 are available from the Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, upon written request.

§ 20.104 Exposure of minors.

(a) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area who is under 18 years of age, to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of 10 percent of the limits specified in the table in paragraph (a) of § 20.101.

(b) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area, who is under 18 years of age to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table II of this part. For purposes of this paragraph, concentrations may be averaged over periods not greater than a week.

(c) The provisions of §§ 20.103(b)(2) and 20.103(c) shall apply to exposures subject to paragraph (b) of this section except that the references in §§ 20.103(b)(2) and 20.103(c) to Appendix B, Table I, Column 1 shall be deemed to be references to Appendix B, Table II, Column 1.

§ 20.105 Permissible levels of radiation in unrestricted areas.

(a) There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem.

(b) Except as authorized by the Commission pursuant to paragraph (a) of this section, no licensee shall possess, use or transfer licensed material in such a manner as to create in any unrestricted area from radioactive material and other sources of radiation in his possession:

(1) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of two millirems in any one hour, or

(2) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 millirems in any seven consecutive days.

§ 20.106 Radioactivity in effluents to unrestricted areas.

(a) A licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in con-

centrations which exceed the limits specified in Appendix "B", Table II of this part, except as authorized pursuant to §20.302 or paragraph (b) of this section. For purposes of this section concentrations may be averaged over a period not greater than one year.

(b) An application for a license or amendment may include proposed limits higher than those specified in paragraph (a) of this section. The Commission will approve the proposed limits if the applicant demonstrates:

(1) That the applicant has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted areas; and

(2) That it is not likely that radioactive material discharged in the effluent would result in the exposure of an individual to concentrations of radioactive material in air or water exceeding the limits specified in Appendix "B", Table II of this part.

(c) An application for higher limits pursuant to paragraph (b) of this section shall include information demonstrating that the applicant has made a reasonable effort to minimize the radioactivity discharged in effluents to unrestricted areas, and shall include, as pertinent:

(1) Information as to flow rates, total volume of effluent, peak concentration of each radionuclide in the effluent, and concentration of each radionuclide in the effluent averaged over a period of one year at the point where the effluent leaves a stack, tube, pipe, or similar conduit;

(2) A description of the properties of the effluents, including:

(i) chemical composition;

(ii) physical characteristics, including suspended solids content in liquid effluents, and nature of gas or aerosol for air effluents;

(iii) the hydrogen ion concentrations (p^H) of liquid effluents; and

(iv) the size range of particulates in effluents released into air.

(3) A description of the anticipated human occupancy in the unrestricted area where the highest concentration of radioactive material from the effluent is expected, and, in the case of a river or stream, a description of water uses downstream from the point of release of the effluent.

(4) Information as to the highest concentration of each radionuclide in an unrestricted area, including anticipated concentrations averaged over a period of one year:

(i) In air at any point of human occupancy; or

(ii) In water at points of use downstream from the point of release of the effluent.

(5) The background concentration of radionuclides in the receiving river or stream prior to the release of liquid effluent.

(6) A description of the environmental monitoring equipment, including sensitivity of the system, and procedures and calculations to determine concentrations of radionuclides in the unrestricted area and possible reconcentrations of radionuclides.

(7) A description of the waste treatment facilities and procedures used to reduce the concentration of radionuclides in effluents prior to their release.

(d) For the purposes of this section the concentration limits in Appendix "B", Table II of this part shall apply at the boundary of the restricted area. The concentration of radioactive material discharged through a stack, pipe or similar conduit may be determined with respect to the point where the material leaves the conduit. If the conduit discharges within the restricted area, the concentration at the boundary may be determined by applying appropriate factors for dilution, dispersion, or decay between the point of discharge and the boundary.

(e) In addition to limiting concentrations in effluent streams, the Commission may limit quantities of radioactive materials released in air or water during a specified period of time if it appears that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed the daily intake resulting from continuous exposure to air or water containing one-third the concentration of radioactive materials specified in Appendix "B", Table II of this part.

(f) The provisions of this section do not apply to disposal of radioactive material into sanitary sewerage systems, which is governed by §20.303.

29 FR 14434

29 FR 14434

25 FR 10914

§ 20.107 Medical diagnosis and therapy.

Nothing in the regulations in this part shall be interpreted as limiting the intentional exposure of patients to radiation for the purpose of medical diagnosis or medical therapy.

§ 20.108 Orders requiring furnishing of bio-assay services.

Where necessary or desirable in order to aid in determining the extent of an

individual's exposure to concentrations of radioactive material, the Commission may incorporate appropriate provisions in any license, directing the licensee to make available to the individual appropriate bio-assay services and to furnish a copy of the reports of such services to the Commission.

PRECAUTIONARY PROCEDURES

§ 20.201 Surveys.

(a) As used in the regulations in this part, "survey" means an evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and equipment, and measurements of levels of radiation or concentrations of radioactive material present.

(b) Each licensee shall make or cause to be made such surveys as may be necessary for him to comply with the regulations in this part.

§ 20.202 Personnel monitoring.

(a) Each licensee shall supply appropriate personnel monitoring equipment to, and shall require the use of such equipment by:

(1) Each individual who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value specified in paragraph (a) of § 20.101.

(2) Each individual under 18 years of age who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 5 percent of the applicable value specified in paragraph (a) of § 20.101.

(3) Each individual who enters a high radiation area.

(b) As used in this part,

(1) "Personnel monitoring equipment" means devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e. g., film badges, pocket chambers, pocket dosimeters, film rings, etc.);

(2) "Radiation area" means any area, accessible to personnel, in which there exists radiation, originating in whole or in part within licensed material, at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems;

(3) "High radiation area" means any area, accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

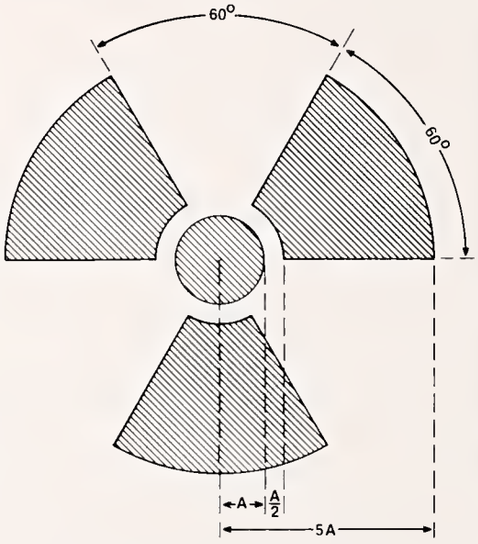
[35 FR 5033]

§ 20.203 Caution signs, labels, signals, and controls.

(a) *General.* (1) Except as otherwise authorized by the Commission, symbols prescribed by this section shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol prescribed by this section is the conventional three-bladed design:

RADIATION SYMBOL

1. Cross-hatched area is to be magenta or purple.
2. Background is to be yellow.



(2) In addition to the contents of signs and labels prescribed in this section, licensees may provide on or near such signs and labels any additional information which may be appropriate in aiding individuals to minimize exposure to radiation or to radioactive material.

(b) *Radiation areas.* Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]
RADIATION AREA

(c) *High radiation areas.* (1) Each high radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]
HIGH RADIATION AREA

(2) Each entrance or access point to a high radiation area shall be:

(i) Equipped with a control device which shall cause the level of radiation to be reduced below that at which an individual might receive a dose of 100 millirems in 1 hour upon entry into the area; or

(ii) Equipped with a control device which shall energize a conspicuous visible or audible alarm signal in such a manner that the individual entering the high radiation area and the licensee or a supervisor of the activity are made aware of the entry; or

(iii) Maintained locked except during periods when access to the area is required, with positive control over each individual entry.

(3) The controls required by subparagraph (2) of this paragraph shall be established in such a way that no individual will be prevented from leaving a high radiation area.

(4) In the case of a high radiation area established for a period of 30 days or less, direct surveillance to prevent unauthorized entry may be substituted for the controls required by subparagraph (2) of this paragraph.

(5) Any licensee, or applicant for a license, may apply to the Commission for approval of methods not included in subparagraphs (2) and (4) of this paragraph for controlling access to high radiation areas. The Commission will approve the proposed alternatives if the licensee or applicant demonstrates that the alternative methods of control will prevent unauthorized entry into a high radiation area, and that the requirement of subparagraph (3) of this paragraph is met.

(d) *Airborne radioactivity areas.* (1) As used in the regulations in this part, "airborne radioactivity area" means (i) any room, enclosure, or operating area in which airborne radioactive materials, composed wholly or partly of licensed material, exist in concentrations in excess of the amounts specified in Appendix B, Table I, Column 1 of this part; or (ii) any room, enclosure, or operating area in which airborne radioactive material composed wholly or partly of licensed material exists in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in Appendix B, Table I, Column 1 of this part.

(2) Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]
AIRBORNE RADIOACTIVITY AREA

(e) *Additional requirements.* (1) Each area or room in which licensed material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in an amount exceeding 10 times the quantity of such material specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]
RADIOACTIVE MATERIAL(S)

(2) Each area or room in which natural uranium or thorium is used or stored in an amount exceeding one-hundred times the quantity specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]
RADIOACTIVE MATERIAL(S)

(f) *Containers.* (1) Except as provided in subparagraph (3) of this paragraph, each container of licensed mate-

[1] Or "Danger."

[25 FR 10914] [35 FR 5033] [35 FR 5033] [35 FR 5033]

rial shall bear a durable, clearly visible label identifying the radioactive contents.

(2) A label required pursuant to subparagraph (1) of this paragraph shall bear the radiation caution symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL". It shall also provide sufficient information[1] to permit individuals handling or using the containers, or working in the vicinity thereof, to take precautions to avoid or minimize exposures.

(3) Notwithstanding the provisions of subparagraph (1) of this paragraph, labeling is not required:

(i) For containers that do not contain licensed materials in quantities greater than the applicable quantities listed in Appendix C of this part.

(ii) For containers containing only natural uranium or thorium in quantities no greater than 10 times the applicable quantities listed in Appendix C of this part.

(iii) For containers that do not contain licensed materials in concentrations greater than the applicable concentrations listed in Column 2, Table I, Appendix B of this part.

(iv) For containers when they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.

(v) For containers when they are in transport and packaged and labeled in accordance with regulations of the * Department of Transportation .

(vi) For containers which are accessible[2] only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

(vii) For manufacturing or process equipment, such as nuclear reactors, reactor components, piping, and tanks.

31 FR 10514

§ 20.204 Same: exceptions.

25 FR 10914

Notwithstanding the provisions of § 20.203,

(a) A room or area is not required to be posted with a caution sign because of the presence of a sealed source provided the radiation level twelve inches from the surface of the source container or housing does not exceed five millirem per hour.

(b) Rooms or other areas in hospitals are not required to be posted with caution signs, and control of entrance or access thereto pursuant to § 20.203(c) is not required, because of the presence of patients containing byproduct material provided that there are personnel in attendance who will take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in the regulations in this part.

35 FR 5033

(c) Caution signs are not required to be posted at areas or rooms containing radioactive materials for periods of less than eight hours provided that (1) the materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in the regulations in this part and; (2) such area or room is subject to the licensee's control.

25 FR 10914

(d) A room or other area is not required to be posted with a caution sign, and control is not required for each entrance or access point to a room or other area which is a high radiation area solely because of the presence of radioactive materials prepared for transport and packaged and labeled in accordance with regulations of the Department of Transportation.

35 FR 5033

§ 20.205 Procedures for picking up, receiving, and opening packages.

39 FR 17972

(a)(1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b)(1) Each licensee, upon receipt of a package of radioactive material, shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, mailgram, or facsimile,† the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group[1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25.000	1000
Special Form	1	20

39 FR 17972

(c)(1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify by telephone and telegraph, mailgram, or facsimile, the director of the appropriate NRC Regional Office listed in Appendix D, and the final delivering carrier.

41 FR 16445

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

39 FR 17972

§ 20.206 Instruction of personnel.

38 FR 22220

Instructions required for individuals working in or frequenting any portion of a restricted area are specified in § 19.12 of this chapter.

[1] As appropriate, the information will include radiation levels, kinds of material, estimate of activity, date for which activity is estimated, mass enrichment, etc.

[2] For example, containers in locations such as water-filled canals, storage vaults, or hot cells.

* Amended 34 FR 19546.

[1] The definitions of "transport group" and "special form" are specified in § 71.4 of this chapter.

†Amended 41 FR 16445.

40 FR 26679

§ 20.207 Storage and control of licensed materials in unrestricted areas.

(a) Licensed materials stored in an unrestricted area shall be secured from unauthorized removal from the place of storage.

(b) Licensed materials in an unrestricted area and not in storage shall be tended under the constant surveillance and immediate control of the licensee.

Waste Disposal

25 FR 10914

§ 20.301 General requirement.

No licensee shall dispose of licensed material except:

(a) By transfer to an authorized recipient as provided in the regulations in Part 30, 40, or 70 of this chapter, whichever may be applicable; or

(b) As authorized pursuant to § 20.302; or

(c) As provided in § 20.303 or § 20.304, applicable respectively to the disposal of licensed material by release into sanitary sewerage systems or burial in soil, or in § 20.106 (Radioactivity in Effluents to Unrestricted Areas).

§ 20.302 Method for obtaining approval of proposed disposal procedures.

*(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

26 FR 352

*(b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the Federal government or by a State government.

36 FR 23138

(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal.

25 FR 10914

§ 20.303 Disposal by release into sanitary sewerage systems.

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(a) It is readily soluble or dispersible in water; and

(b) The quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of subparagraphs (1) or (2) of this paragraph:

(1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table I, Column 2 of this part; or

(2) Ten times the quantity of such material specified in Appendix C of this part; and

(c) The quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in Appendix B, Table I, Column 2 of this part; and

(d) The gross quantity of licensed and other radioactive material released into the sewerage system by the licensee does not exceed one curie per year.

Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

25 FR 10914

§ 20.304 Disposal by burial in soil.

No licensee shall dispose of licensed material by burial in soil unless:

(a) The total quantity of licensed and other radioactive materials buried at any one location and time does not exceed, at the time of burial, 1,000 times the amount specified in Appendix C of this part; and

(b) Burial is at a minimum depth of four feet; and

(c) Successive burials are separated by distances of at least six feet and not more than 12 burials are made in any year.

§ 20.305 Treatment or disposal by incineration.

No licensee shall treat or dispose of licensed material by incineration except as specifically approved by the Commission pursuant to §§ 20.106(b) and 20.302.

Records, Reports, and Notification

39 FR 17972

§ 20.401 Records of surveys, radiation monitoring, and disposal.

(a) Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required under § 20.202 of the regulations in this part. Such records shall be kept on Form NRC-5, in accordance with the instructions contained in that form or on clear and legible records containing all the information required by Form NRC-5. The doses entered on the forms or records shall be for periods of time not exceeding one calendar quarter.

(b) Each licensee shall maintain records in the same units used in this part, showing the results of surveys required by § 20.201(b), monitoring required by §§ 20.205(b) and 20.205(c), and disposals made under §§ 20.302, 20.303, and 20.304.

(c) (1) Records of individual exposure to radiation and to radioactive material which must be maintained pursuant to the provisions of paragraph (a) of this section and records of bioassays, including results of whole body counting examinations, made pursuant to § 20.108, shall be preserved until the Commission authorizes disposition.

41 FR 18300

(2) Records of the results of surveys and monitoring which must be maintained pursuant to paragraph (b) of this section shall be preserved for two years after completion of the survey except that the following records shall be maintained until the Commission authorizes their disposition: (i) records of the results of surveys to determine compliance with § 20.103(a); (ii) in the absence of personnel monitoring data, records of the results of surveys to determine external radiation dose; and (iii) records of the results of surveys used to evaluate the release of radioactive effluents to the environment.

(3) Records of disposal of licensed material made pursuant to §§ 20.302, 20.303, or 20.304 shall be maintained until the Commission authorizes their disposition.

(4) Records which must be maintained pursuant to this part may be the original or a reproduced copy or microform if such reproduced copy or microform is duly authenticated by authorized personnel and the microform is capable of producing a clear and legible copy after storage for the period specified by Commission regulations.

(5) If there is a conflict between the Commission's regulations in this part, license condition, or technical specification, or other written Commission approval or authorization pertaining to the retention period for the same type of record, the retention period specified in the regulations in this part for such records shall apply unless the Commission pursuant to § 20.501, has granted a specific exemption from the record retention requirements specified in the regulations in this part.

34 FR 7500

§ 20.402 Reports of theft or loss of licensed material.

(a) Each licensee shall report by telephone and telegraph, mailgram, or facsimile,† to the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, immediately after its occurrence becomes known to the licensee, any loss or theft of licensed material in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

41 FR 16445

(b) Each licensee who is required to make a report pursuant to paragraph (a) of this section shall, within thirty (30) days after he learns of the loss or theft, make a report in writing to the appropriate NRC Regional Office listed in Appendix D with copies to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, setting forth the following information:

*Redesignated 36 FR 23138.

†Amended 41 FR 16445.

(1) A description of the licensed material involved, including kind, quantity, chemical, and physical form;

(2) A description of the circumstances under which the loss or theft occurred;

(3) A statement of disposition or probable disposition of the licensed material involved;

(4) Radiation exposures to individuals, circumstances under which the exposures occurred, and the extent of possible hazard to persons in unrestricted areas;

(5) Actions which have been taken, or will be taken, to recover the material; and

(6) Procedures or measures which have been or will be adopted to prevent a recurrence of the loss or theft of licensed material.

(c) Subsequent to filing the written report the licensee shall also report any substantive additional information on the loss or theft which becomes available to the licensee, within 30 days after he learns of such information.

(d) Any report filed with the Commission pursuant to this section shall be so prepared that names of individuals who may have received exposure to radiation are stated in a separate part of the report.

34 FR 7500

41 FR 16445

§ 20.403 Notifications of incidents.

(a) *Immediate notification.* Each licensee shall immediately notify by telephone and telegraph, mailgram, or facsimile, the Director of the appropriate NRC Regional Office listed in Appendix

D of any incident involving byproduct, source, or special nuclear material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the whole body of any individual of 150 rems or more of radiation; or exposure of the feet, ankles, hands or forearms of any individual to 375 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one working week or more of the operation of any facilities affected; or

(4) Damage to property in excess of $100,000.

(b) *Twenty-four hour notification.* Each licensee shall within 24 hours notify by telephone and telegraph, mailgram, or facsimile, the Director of the appropriate NRC Regional Office listed in Appendix D of any incident involving licensed material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 5 rems or more of radiation; exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 500 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one day or more of the operation of any facilities affected; or

(4) Damage to property in excess of $1,000.

(c) Any report filed with the Commission pursuant to this section shall be prepared so that names of individuals who have received exposure to radiation will be stated in a separate part of the report.

§ 20.404 [Deleted 38 FR 22220.]

§ 20.405 Reports of overexposures and excessive levels and concentrations.

(a) In addition to any notification required by § 20.403, each licensee shall make a report in writing within 30 days to the appropriate NRC Regional Office listed in Appendix D with a copy to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, of:

(1) each exposure of an individual to radiation in excess of the applicable limits in §§ 20.101 or 20.104 (a) or the license; (2) each exposure of an individual to radioactive material in excess of the applicable limits in §§ 20.103(a)(1), 20.103(a)(2), 20.104(b) or the license; (3) levels of radiation or concentrations of radioactive material in a restricted area in excess of any other applicable limit in the license; (4) any incident for which notification is required by § 20.403; and (5) levels of radiation or concentrations of radioactive material (whether or not involving excessive exposure of any individual) in an unrestricted area in excess of ten times any applicable limit set forth in this part or in the license. Each report required under this paragraph shall describe the extent of exposure of persons to radiation or to radioactive material, including estimates of each individual's exposure as required by paragraph (b) of this section; levels of radiation and concentrations of radioactive material involved; the cause of the exposure, levels or concentrations; and corrective steps taken or planned to assure against a recurrence.

(b) Any report filed with the Commission pursuant to this section shall include for each individual exposed the name, social security number, and date of birth; and an estimate of the individual's exposure. The report shall be prepared so that this information is stated in a separate part of the report.

(c) [Deleted 38 FR 22220.]

§ 20.406 [Deleted 38 FR 22220.]

§ 20.407 Personnel exposure and monitoring reports.

(a) This section applies to each person licensed by the Commission or the Atomic Energy Commission to:

(1) Operate a nuclear reactor designed to produce electrical or heat energy pursuant to § 50.21(b) or § 50.22 of this chapter or a testing facility as defined in § 50.2(r) of this chapter;

(2) Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter;

(3) Possess or use at any one time, for purposes of fuel processing, fabrication, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium or any combination thereof pursuant to Part 70 of this chapter; or

(4) Possess or use at any one time, for processing or manufacturing for distribution pursuant to Part 30, 32, or 33 of this chapter, byproduct material in quantities exceeding anyone of the following quantities:

Radionuclide[1]	*Quantity in curies*
Cesium-137	1
Cobalt-60	1
Gold-198	100
Iodine-131	1
Iridium-192	10
Krypton-85	1,000
Promethium-147	10
Technetium-99m	1,000

(b) Each person described in paragraph (a) of this section shall, within the first quarter of each calendar year, submit to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555,† the following reports, applicable to the described licensed activities covering the preceding calendar year: [2]

(1) A report of either (i) the total number of individuals for whom personnel monitoring was required under §§ 20.202(a) or 34.33(a) of this chapter during the calendar year, or (ii) the total number of individuals for whom personnel monitoring was provided during the calendar year; *Provided,* that such total includes at least the number of individuals required to be reported under paragraph (b)(1)(i) of this section. The report shall indicate whether it is submitted in accordance with paragraph (b)(1)(i) or (ii) of this section.

(2) A statistical summary report of the personnel monitoring information recorded by the licensee for individuals for whom personnel monitoring was either required or provided, as described in § 20.407(b)(1), indicating the number of individuals whose total whole body exposure recorded during the previous calendar year was in each of the following estimated exposure ranges:

Estimated Whole Body Exposure Range (Rems)[3]	*Number of individuals in each range*
No measurable exposure	
Measurable exposure less than 0.1	
0.1 to 0.25	
0.25 to 0.5	
0.5 to 0.75	
0.75 to 1	
1 to 2	
2 to 3	
3 to 4	
4 to 5	
5 to 6	
6 to 7	
7 to 8	
8 to 9	
9 to 10	
10 to 11	
11 to 12	
12+	

The low exposure range data are required in order to obtain better information about the exposures actually recorded. This section does not require improved measurements.

§ 20.408 Reports of personnel exposure on termination of employment or work.

When an individual terminates employment with a licensee subject to § 20.407, or an individual assigned to work in such a licensee's facility, but not employed by the licensee, completes his work assignment in the licensee's facility, the licensee shall furnish* to the Director of Inspection and Enforcement,† U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, a report of the individual's exposure to radiation and radioactive material, incurred during the.

[1] The Commission may require, as a license condition, or by rule, regulation or order pursuant to § 20.502, reports from licensees who are licensed to use radionuclides not on this list, in quantities sufficient to cause comparable radiation levels.

†Amended 41 FR 16445.

[2] A licensee whose license expires or terminates prior to, or on the last day of the calendar year, shall submit reports at the expiration or termination of the license, covering that part of the year during which the license was in effect.

[3] Individual values exactly equal to the values separating Exposure Ranges shall be reported in the higher range.

* Amended 38 FR 22220.

34 FR 5254

period of employment or work assignment in the licensee's facility, containing information recorded by the licensee pursuant to §§ 20.401(a) and 20.108. Such report shall be furnished within 30 days after the exposure of the individual has been determined by the licensee or 90 days after the date of termination of employment or work assignment, whichever is earlier.

38 FR 22220

§ 20.409 Notifications and reports to individuals.

(a) Requirements for notifications and reports to individuals of exposure to radiation or radioactive material are specified in § 19.13 of this chapter.

(b) When a licensee is required pursuant to §§ 20.405 or 20.408 to report to the Commission any exposure of an individual to radiation or radioactive material, the licensee shall also notify the individual. Such notice shall be transmitted at a time not later than the transmittal to the Commission, and shall comply with the provisions of § 19.13(a) of this chapter.

EXCEPTIONS AND ADDITIONAL REQUIREMENTS

25 FR 10914

§ 20.501 Applications for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 20.502 Additional requirements.

The Commission may, by rule, regulation, or order, impose upon any licensee such requirements, in addition to those established in the regulations in this part, as it deems appropriate or necessary to protect health or to minimize danger to life or property.

40 FR 8774

§ 20.601 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

NOTE.—The reporting and record keeping requirements contained in this part have been approved by the General Accounting Office under B–180225 (R0043), (R0044), and (R0084).

APPENDIX A [Reserved]

APPENDIX B

Concentrations in Air and Water Above Natural Background

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Actinium (89)	Ac 227	S	2×10^{-12}	6×10^{-5}	8×10^{-14}	2×10^{-6}
		I	3×10^{-11}	9×10^{-3}	9×10^{-13}	3×10^{-4}
	Ac 228	S	8×10^{-8}	3×10^{-3}	3×10^{-9}	9×10^{-5}
		I	2×10^{-8}	3×10^{-3}	6×10^{-10}	9×10^{-5}
Americium (95)	Am 241	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		* I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 242m	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	3×10^{-10}	3×10^{-3}	9×10^{-12}	9×10^{-5}
	Am 242	S	4×10^{-8}	4×10^{-3}	1×10^{-9}	1×10^{-4}
		I	5×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Am 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 244	S	4×10^{-6}	1×10^{-1}	1×10^{-7}	5×10^{-3}
		I	2×10^{-5}	1×10^{-1}	8×10^{-7}	5×10^{-3}
Antimony (51)	Sb 122	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
	Sb 124	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	2×10^{-8}	7×10^{-4}	7×10^{-10}	2×10^{-5}
	Sb 125	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	3×10^{-3}	9×10^{-10}	1×10^{-4}
Argon (18)	A 37	Sub [2]	6×10^{-3}	----------	1×10^{-4}	----------
	A 41	Sub	2×10^{-6}	----------	4×10^{-8}	----------
Arsenic (33)	As 73	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	5×10^{-4}
		I	4×10^{-7}	1×10^{-2}	1×10^{-8}	5×10^{-4}
	As 74	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	1×10^{-7}	2×10^{-3}	4×10^{-9}	5×10^{-5}
	As 76	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	As 77	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Astatine (85)	At 211	S	7×10^{-9}	5×10^{-5}	2×10^{-10}	2×10^{-6}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
Barium (56)	Ba 131	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ba 140	S	1×10^{-7}	8×10^{-4}	4×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	2×10^{-5}
Berkelium (97)	Bk 249	S	9×10^{-10}	2×10^{-2}	3×10^{-11}	6×10^{-4}
		I	1×10^{-7}	2×10^{-2}	4×10^{-9}	6×10^{-4}
	Bk 250	S	1×10^{-7}	6×10^{-3}	5×10^{-9}	2×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Beryllium (4)	Be 7	S	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	1×10^{-6}	5×10^{-2}	4×10^{-8}	2×10^{-3}
Bismuth (83)	Bi 206	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	1×10^{-7}	1×10^{-3}	5×10^{-9}	4×10^{-5}
	Bi 207	S	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
		I	1×10^{-8}	2×10^{-3}	5×10^{-10}	6×10^{-5}
	Bi 210	S	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
		I	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Bi 212	S	1×10^{-7}	1×10^{-2}	3×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	7×10^{-9}	4×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Bromine (35)	Br 82	S	1×10^{-6}	8×10^{-3}	4×10^{-8}	3×10^{-4}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Cadmium (48)	Cd 109	S	5×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
		I	7×10^{-8}	5×10^{-3}	3×10^{-9}	2×10^{-4}
	Cd 115m	S	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
	Cd 115	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Calcium (20)	Ca 45	S	3×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Ca 47	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
Californium (98)	Cf 249	S	2×10^{-12}	1×10^{-4}	5×10^{-14}	4×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cf 250	S	5×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 251	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 252	* S	6×10^{-12}	2×10^{-4}	2×10^{-13}	7×10^{-6}
		* I	3×10^{-11}	2×10^{-4}	1×10^{-12}	7×10^{-6}
	Cf 253	S	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
		I	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
	Cf 254	S	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
		I	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
Carbon (6)	C 14	S	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	(CO_2)	Sub	5×10^{-5}	----------	1×10^{-6}	----------
Cerium (58)	Ce 141	S	4×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	3×10^{-3}	5×10^{-9}	9×10^{-5}
	Ce 143	S	3×10^{-7}	1×10^{-3}	9×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	Ce 144	S	1×10^{-8}	3×10^{-4}	3×10^{-10}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Cesium (55)	Cs 131	S	1×10^{-5}	7×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-6}	3×10^{-2}	1×10^{-7}	9×10^{-4}
	Cs 134m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
	Cs 134	S	4×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	4×10^{-5}
	Cs 135	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	9×10^{-8}	7×10^{-3}	3×10^{-9}	2×10^{-4}
	Cs 136	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
	Cs 137	S	6×10^{-8}	4×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-8}	1×10^{-3}	5×10^{-10}	4×10^{-5}
Chlorine (17)	Cl 36	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
		I	2×10^{-8}	2×10^{-3}	8×10^{-10}	6×10^{-5}
	Cl 38	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
Chromium (24)	Cr 51	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	2×10^{-6}	5×10^{-2}	8×10^{-8}	2×10^{-3}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Cobalt (27)	Co 57	S	3×10^{-6}	2×10^{-2}	1×10^{-7}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	6×10^{-9}	4×10^{-4}
	Co 58m	S	2×10^{-5}	8×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	6×10^{-2}	3×10^{-7}	2×10^{-3}
	Co 58	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-8}	3×10^{-3}	2×10^{-9}	9×10^{-5}
	Co 60	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	9×10^{-9}	1×10^{-3}	3×10^{-10}	3×10^{-5}
Copper (29)	Cu 64	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Curium (96)	Cm 242	S	1×10^{-10}	7×10^{-4}	4×10^{-12}	2×10^{-5}
		* I	2×10^{-10}	7×10^{-4}	6×10^{-12}	2×10^{-5}
	Cm 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	5×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cm 244	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cm 245	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 246	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 247	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	6×10^{-4}	4×10^{-12}	2×10^{-5}
	Cm 248	S	6×10^{-13}	1×10^{-5}	2×10^{-14}	4×10^{-7}
		I	1×10^{-11}	4×10^{-5}	4×10^{-13}	1×10^{-6}
	Cm 249	S	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
		I	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
Dysprosium (66)	Dy 165	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
	Dy 166	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Einsteinium (99)	Es 253	S	8×10^{-10}	7×10^{-4}	3×10^{-11}	2×10^{-5}
		I	6×10^{-10}	7×10^{-4}	2×10^{-11}	2×10^{-5}
	Es 254m	S	5×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
		I	6×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
	Es 254	S	2×10^{-11}	4×10^{-4}	6×10^{-13}	1×10^{-5}
		I	1×10^{-10}	4×10^{-4}	4×10^{-12}	1×10^{-5}
	Es 255	S	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	4×10^{-10}	8×10^{-4}	1×10^{-11}	3×10^{-5}
Erbium (68)	Er 169	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	Er 171	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Europium (63)	Eu 152	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	(T/2 = 9.2 hrs)	I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Eu 152	S	1×10^{-8}	2×10^{-3}	4×10^{-10}	8×10^{-5}
	(T/2 = 13 yrs)	I	2×10^{-8}	2×10^{-3}	6×10^{-10}	8×10^{-5}
	Eu 154	S	4×10^{-9}	6×10^{-4}	1×10^{-10}	2×10^{-5}
		I	7×10^{-9}	6×10^{-4}	2×10^{-10}	2×10^{-5}
	Eu 155	S	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
		I	7×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Fermium (100)	Fm 254	S	6×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
		I	7×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Fm 255	S	2×10^{-8}	1×10^{-3}	6×10^{-10}	3×10^{-5}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	3×10^{-5}
	Fm 256	S	3×10^{-9}	3×10^{-5}	1×10^{-10}	9×10^{-7}
		I	2×10^{-9}	3×10^{-5}	6×10^{-11}	9×10^{-7}
Fluorine (9)	F 18	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
Gadolinium (64)	Gd 153	S	2×10^{-7}	6×10^{-3}	8×10^{-9}	2×10^{-4}
		I	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Gd 159	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Gallium (31)	Ga 72	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Germanium (32)	Ge 71	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
Gold (79)	Au 196	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
	Au 198	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Au 199	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	8×10^{-7}	4×10^{-3}	3×10^{-8}	2×10^{-4}
Hafnium (72)	Hf 181	S	4×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
		I	7×10^{-8}	2×10^{-3}	3×10^{-9}	7×10^{-5}
Holmium (67)	Ho 166	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Hydrogen (1)	H3	S	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		I	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		Sub	2×10^{-3}		4×10^{-5}	
Indium (49)	In 113m	S	8×10^{-6}	4×10^{-2}	3×10^{-7}	1×10^{-3}
		I	7×10^{-6}	4×10^{-2}	2×10^{-7}	1×10^{-3}
	In 114m	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
	In 115m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	In 115	S	2×10^{-7}	3×10^{-3}	9×10^{-9}	9×10^{-5}
		I	3×10^{-8}	3×10^{-3}	1×10^{-9}	9×10^{-5}
Iodine (53)	I 125	S	5×10^{-9}	4×10^{-5}	8×10^{-11}	2×10^{-7}
		I	2×10^{-7}	6×10^{-3}	6×10^{-9}	2×10^{-4}
	I 126	S	8×10^{-9}	5×10^{-5}	9×10^{-11}	3×10^{-7}
		I	3×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	I 129	S	2×10^{-9}	1×10^{-5}	2×10^{-11}	6×10^{-8}
		I	7×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
	I 131	S	9×10^{-9}	6×10^{-5}	1×10^{-10}	3×10^{-7}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	I 132	S	2×10^{-7}	2×10^{-3}	3×10^{-9}	8×10^{-6}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	I 133	S	3×10^{-8}	2×10^{-4}	4×10^{-10}	1×10^{-6}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	I 134	S	5×10^{-7}	4×10^{-3}	6×10^{-9}	2×10^{-5}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Iodine (53)	I 134	I	3×10^{-6}	2×10^{-2}	1×10^{-7}	6×10^{-4}
	I 135	S	1×10^{-7}	7×10^{-4}	1×10^{-9}	4×10^{-6}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
Iridium (77)	Ir 190	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ir 192	S	1×10^{-7}	1×10^{-3}	4×10^{-9}	4×10^{-5}
		I	3×10^{-8}	1×10^{-3}	9×10^{-10}	4×10^{-5}
	Ir 194	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
Iron (26)	Fe 55	S	9×10^{-7}	2×10^{-2}	3×10^{-8}	8×10^{-4}
		I	1×10^{-6}	7×10^{-2}	3×10^{-8}	2×10^{-3}
	Fe 59	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	5×10^{-5}
Krypton (36)	Kr 85m	Sub	6×10^{-6}	----------	1×10^{-7}	----------
	Kr 85	Sub	1×10^{-5}	----------	3×10^{-7}	----------
	Kr 87	Sub	1×10^{-6}	----------	2×10^{-8}	----------
	Kr 88	Sub	1×10^{-6}	----------	2×10^{-8}	----------
Lanthanum (57)	La 140	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	1×10^{-7}	7×10^{-4}	4×10^{-9}	2×10^{-5}
Lead (82)	Pb 203	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	Pb 210	S	1×10^{-10}	4×10^{-6}	4×10^{-12}	1×10^{-7}
		I	2×10^{-10}	5×10^{-3}	8×10^{-12}	2×10^{-4}
	Pb 212	S	2×10^{-8}	6×10^{-4}	6×10^{-10}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
Lutetium (71)	Lu 177	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Manganese (25)	Mn 52	S	2×10^{-7}	1×10^{-3}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Mn 54 *	S	4×10^{-7}	4×10^{-3}	1×10^{-8}	1×10^{-4}
		I	4×10^{-8}	3×10^{-3}	1×10^{-9}	1×10^{-4}
	Mn 56	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Mercury (80)	Hg 197m	S	7×10^{-7}	6×10^{-3}	3×10^{-8}	2×10^{-4}
		I	8×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Hg 197	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
	Hg 203	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
Molybdenum (42)	Mo 99	S	7×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Neodymium (60)	Nd 144	S	8×10^{-11}	2×10^{-3}	3×10^{-12}	7×10^{-5}
		I	3×10^{-10}	2×10^{-3}	1×10^{-11}	8×10^{-5}
	Nd 147	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	6×10^{-5}
	Nd 149	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	1×10^{-6}	8×10^{-3}	5×10^{-8}	3×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Neptunium (93)	Np 237	S	4×10^{-12}	9×10^{-5}	1×10^{-13}	3×10^{-6}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	Np 239	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	7×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
Nickel (28)	Ni 59	S	5×10^{-7}	6×10^{-3}	2×10^{-8}	2×10^{-4}
		I	8×10^{-7}	6×10^{-2}	3×10^{-8}	2×10^{-3}
	Ni 63	S	6×10^{-8}	8×10^{-4}	2×10^{-9}	3×10^{-5}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	7×10^{-4}
	Ni 65	S	9×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Niobium (Columbium) (41).	Nb 93m	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Nb 95	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	3×10^{-9}	1×10^{-4}
	Nb 97	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
Osmium (76)	Os 185	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	7×10^{-5}
	Os 191m	S	2×10^{-5}	7×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	7×10^{-2}	3×10^{-7}	2×10^{-3}
	Os 191	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Os 193	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	9×10^{-9}	5×10^{-5}
Palladium (46)	Pd 103	S	1×10^{-6}	1×10^{-2}	5×10^{-8}	3×10^{-4}
		I	7×10^{-7}	8×10^{-3}	3×10^{-8}	3×10^{-4}
	Pd 109	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
Phosphorus (15)	P 32	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	8×10^{-8}	7×10^{-4}	3×10^{-9}	2×10^{-5}
Platinum (78)	Pt 191	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Pt 193m	S	7×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
	Pt 193 *	S	1×10^{-6}	3×10^{-2}	4×10^{-8}	9×10^{-4}
		I	3×10^{-7}	5×10^{-2}	1×10^{-8}	2×10^{-3}
	Pt 197m	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
	Pt 197	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Plutonium (94)	Pu 238	S	2×10^{-12}	1×10^{-4}	7×10^{-14}	5×10^{-6}
		I	3×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 239	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 240	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 241	S	9×10^{-11}	7×10^{-3}	3×10^{-12}	2×10^{-4}
		I	4×10^{-8}	4×10^{-2}	1×10^{-9}	1×10^{-3}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Plutonium (94)	Pu 242	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	9×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 243	S	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
		I	2×10^{-6}	1×10^{-2}	8×10^{-8}	3×10^{-4}
	Pu 244	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	3×10^{-11}	3×10^{-4}	1×10^{-12}	1×10^{-5}
Palanium (84)	Pa 210	S	5×10^{-10}	2×10^{-3}	2×10^{-11}	7×10^{-7}
		I	2×10^{-10}	8×10^{-4}	7×10^{-12}	3×10^{-5}
Patassium (19)	K 42	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Praseadymium (59)	Pr 142	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Pr 143	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
Pramethium (61)	Pm 147	S	6×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
		I	1×10^{-7}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Pm 149	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Prataactinium (91)	Pa 230	S	2×10^{-9}	7×10^{-3}	6×10^{-11}	2×10^{-4}
		I	8×10^{-10}	7×10^{-3}	3×10^{-11}	2×10^{-4}
	Pa 231	S	1×10^{-12}	3×10^{-5}	4×10^{-14}	9×10^{-7}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	2×10^{-5}
	Pa 233	S	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	3×10^{-3}	6×10^{-9}	1×10^{-4}
Radium (88)	Ra 223	S	2×10^{-9}	2×10^{-5}	6×10^{-11}	7×10^{-7}
		I	2×10^{-10}	1×10^{-4}	8×10^{-12}	4×10^{-6}
	Ra 224	S	5×10^{-9}	7×10^{-5}	2×10^{-10}	2×10^{-6}
		I	7×10^{-10}	2×10^{-4}	2×10^{-11}	5×10^{-6}
	Ra 226	S	3×10^{-11}	4×10^{-7}	3×10^{-12}	3×10^{-8}
		I	5×10^{-11}	9×10^{-4}	2×10^{-12}	3×10^{-5}
	Ra 228	S	7×10^{-11}	8×10^{-7}	2×10^{-12}	3×10^{-8}
		I	4×10^{-11}	7×10^{-4}	1×10^{-12}	3×10^{-5}
Radan (86)	Rn 220	S	3×10^{-7}		1×10^{-8}	
	Rn 222 [3] ***		*** 3×10^{-8}		3×10^{-9}	
Rhenium (75)	Re 183	S	3×10^{-6}	2×10^{-2}	9×10^{-8}	6×10^{-4}
		I	2×10^{-7}	8×10^{-3}	5×10^{-9}	3×10^{-4}
	Re 186	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Re 187	S	9×10^{-6}	7×10^{-2}	3×10^{-7}	3×10^{-3}
		I	5×10^{-7}	4×10^{-2}	2×10^{-8}	2×10^{-3}
	Re 188	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Rhadium (45)	Rh 103m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	6×10^{-5}	3×10^{-1}	2×10^{-6}	1×10^{-2}
	Rh 105	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Rubidium (37)	Rb 86	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	7×10^{-8}	7×10^{-4}	2×10^{-9}	2×10^{-5}
	Rb 87	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	7×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Ruthenium (44)	Ru 97	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
	Ru 103	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	8×10^{-8}	2×10^{-3}	3×10^{-9}	8×10^{-5}
	Ru 105	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Ru 106	S	8×10^{-8}	4×10^{-4}	3×10^{-9}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Samarium (62)	5m 147	S	7×10^{-11}	2×10^{-3}	2×10^{-12}	6×10^{-5}
		I	3×10^{-10}	2×10^{-3}	9×10^{-12}	7×10^{-5}
	Sm 151	S	6×10^{-8}	1×10^{-2}	2×10^{-9}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Sm 153	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Scandium (21)	Sc 46	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	8×10^{-10}	4×10^{-5}
	Sc 47	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
	Sc 48	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Selenium (34)	Se 75	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
		I	1×10^{-7}	8×10^{-3}	4×10^{-9}	3×10^{-4}
Silican (14)	Si 31	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
		I	1×10^{-6}	6×10^{-3}	3×10^{-8}	2×10^{-4}
Silver (47)	Ag 105	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	8×10^{-8}	3×10^{-3}	3×10^{-9}	1×10^{-4}
	Ag 110m	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-8}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Ag 111	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Sodium (11)	Na 22	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	9×10^{-9}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Na 24	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Strantium (38)	Sr 85m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
		I	3×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
	Sr 85	S	2×10^{-7}	3×10^{-3}	8×10^{-9}	1×10^{-4}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Sr 89	S	3×10^{-8}	3×10^{-4}	3×10^{-10}	3×10^{-6}
		I	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Sr 90	S	1×10^{-9}	1×10^{-5}	3×10^{-11}	3×10^{-7}
		I	5×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Sr 91	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	1×10^{-3}	9×10^{-9}	5×10^{-5}
	Sr 92	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Sulfur (16)	S 35	S	3×10^{-7}	2×10^{-3}	9×10^{-9}	6×10^{-5}
		I	3×10^{-7}	8×10^{-3}	9×10^{-9}	3×10^{-4}
Tantalum (73)	Ta 182	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	7×10^{-10}	4×10^{-5}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Technetium (43)	Tc 96m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	3×10^{-5}	3×10^{-1}	1×10^{-6}	1×10^{-2}
	Tc 96	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Tc 97m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-7}	5×10^{-3}	5×10^{-9}	2×10^{-4}
	Tc 97	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Tc 99m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	1×10^{-5}	8×10^{-2}	5×10^{-7}	3×10^{-3}
	Tc 99	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
Tellurium (52)	Te 125m	S	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	Te 127m	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	4×10^{-8}	2×10^{-3}	1×10^{-9}	5×10^{-5}
	Te 127	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Te 129m	S	8×10^{-8}	1×10^{-3}	3×10^{-9}	3×10^{-5}
		I	3×10^{-8}	6×10^{-4}	1×10^{-9}	2×10^{-5}
	Te 129	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	Te 131m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
	Te 132	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Terbium (65)	Tb 160	S	1×10^{-7}	1×10^{-3}	3×10^{-9}	4×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
Thallium (81)	Tl 200	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Tl 201	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Tl 202	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	7×10^{-5}
	Tl 204	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	2×10^{-3}	9×10^{-10}	6×10^{-5}
Thorium (90) *	Th 227	S	3×10^{-10}	5×10^{-4}	1×10^{-11}	2×10^{-5}
		I	2×10^{-10}	5×10^{-4}	6×10^{-12}	2×10^{-5}
	Th 228	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	6×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
	Th 230	S	2×10^{-12}	5×10^{-5}	8×10^{-14}	2×10^{-6}
		I	1×10^{-11}	9×10^{-4}	3×10^{-13}	3×10^{-5}
*	Th 231	S	1×10^{-6}	7×10^{-3}	5×10^{-8}	2×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Th 232	S	3×10^{-11}	5×10^{-5}	1×10^{-12}	2×10^{-6}
		I	3×10^{-11}	1×10^{-3}	1×10^{-12}	4×10^{-5}
†*	Th natural	S	6×10^{-11}	6×10^{-5}	2×10^{-12}	2×10^{-6}
			6×10^{-11}	6×10^{-4}	2×10^{-12}	2×10^{-5}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Thorium (90)	Th 234	S	6×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	3×10^{-8}	5×10^{-4}	1×10^{-9}	2×10^{-5}
Thulium (69)	Tm 170	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
	Tm 171	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	8×10^{-9}	5×10^{-4}
Tin (50)	Sn 113	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	8×10^{-5}
	Sn 125	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	8×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Tungsten (Wolfram) (74)	W 181	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	4×10^{-9}	3×10^{-4}
	W 185	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	W 187	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Uranium (92)	U 230	S	3×10^{-10}	1×10^{-4}	1×10^{-11}	5×10^{-6}
		I	1×10^{-10}	1×10^{-4}	4×10^{-12}	5×10^{-6}
	U 232	S	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
		I	3×10^{-11}	8×10^{-4}	9×10^{-13}	3×10^{-5}
	U 233	S	5×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
**	U 234	S[4]	6×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
**	U 235	S[4]	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	U 236	S	6×10^{-10}	1×10^{-3}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	4×10^{-12}	3×10^{-5}
**	U 238	S[4]	7×10^{-11}	1×10^{-3}	3×10^{-12}	4×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	4×10^{-5}
	U 240	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
**	U-natural	S[4]	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
Vanadium (23)	V 48	S	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
		I	6×10^{-8}	8×10^{-4}	2×10^{-9}	3×10^{-5}
Xenon (54)	Xe 131m	Sub	2×10^{-5}	----------	4×10^{-7}	----------
	Xe 133	Sub	1×10^{-5}	----------	3×10^{-7}	----------
	Xe 133m	Sub	1×10^{-5}	----------	3×10^{-7}	----------
	Xe 135	Sub	4×10^{-6}	----------	1×10^{-7}	----------
Ytterbium (70)	Yb 175	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Yttrium (39)	Y 90	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	Y 91m	S	2×10^{-5}	1×10^{-1}	8×10^{-7}	3×10^{-3}
		I	2×10^{-5}	1×10^{-1}	6×10^{-7}	3×10^{-3}
	Y 91	S	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
		I	3×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Y 92	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Y 93	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]		Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Zinc (30)	Zn 65	S	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
	Zn 69m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Zn 69	S	7×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	9×10^{-6}	5×10^{-2}	3×10^{-7}	2×10^{-3}
Zirconium (40)	Zr 93	S	1×10^{-7}	2×10^{-2}	4×10^{-9}	8×10^{-4}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Zr 95	S	1×10^{-7}	2×10^{-3}	4×10^{-9}	6×10^{-5}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	6×10^{-5}
	Zr 97	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	9×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Any single radianuclide nat listed abave with decay made ather than alpha emissian ar spantaneaus fissian and with radiaactive half-life less than 2 haurs.	----------	Sub	1×10^{-6}	----------	3×10^{-8}	----------
Any single radianuclide nat listed abave with decay made ather than alpha emissian ar spantaneaus fissian and with radiaactive half-life greater than 2 haurs.	----------		3×10^{-9}	9×10^{-5}	1×10^{-10}	3×10^{-6}
Any single radianuclide nat listed abave, which decays by alpha emissian ar spantaneaus fisslan.	----------		6×10^{-13}	4×10^{-7}	2×10^{-14}	3×10^{-8}

[1] Soluble (S); Insoluble (I).

[2] "Sub" means that values given are for submersion in a semispherical infinite cloud of airborne material.

[3] These radon concentrations are appropriate for protection from radon-222 combined with its short-lived daughters. Alternatively, the value in Table I may be replaced by one-third (⅓) "working level." (A "working level" is defined as any combination of short-lived radon-222 daughters, polonium-218, lead-214, bismuth-214 and polonium-214, in one liter of air, without regard to the degree of equilibrium, that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.) The Table II value may be replaced by one-thirtieth (1/30) of a "working level." The limit on radon-222 concentrations in restricted areas may be based on an annual average.

‡4. For soluble mixtures of U–238, U–234 and U–235 in air chemical toxicity may be the limiting factor. If the percent by weight (enrichment) of U–235 is less than 5, the concentration value for a 40-hour workweek, Table I, is 0.2 milligrams uranium per cubic meter of air average. For any enrichment, the product of the average concentration and time of exposure during a 40-hour workweek shall not exceed 8×10^{-8} SA μCi-hr/ml, where SA is the specific activity of the uranium inhaled. The concentration value for Table II is 0.007 milligrams uranium per cubic meter of air. The specific activity for natural uranium is 6.77×10^{-7} curies per gram U. The specific activity for other mixtures of U–238, U–235 and U–234, if not known, shall be:

$SA = 3.6 \times 10^{-7}$ curies/gram U (U-depleted $E \geq 0.72$)

$SA = (0.4 + 0.38\,E + 0.0034\,E^2)\ 10^{-6}$

where E is the percentage by weight of U–235, expressed as percent.

*Amended 37 FR 23319.

**Amended 39 FR 23990; footnote redesignated 40 FR 50704.

***Amended 40 FR 50704.

†Amended 38 FR 29314.

‡Amended 39 FR 25463; redesignated 40 FR 50704.

25 FR 10914

39 FR 23990

40 FR 50704

NOTE TO APPENDIX B

NOTE: In any case where there is a mixture in air or water of more than one radionuclide, the limiting values for purposes of this Appendix should be determined as follows:

1. If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed "1" (i.e., "unity").

EXAMPLE: If radionuclides A, B, and C are present in concentrations C_A, C_B, and C_C, and if the applicable MPC's, are MPC_A, and MPC_B, and MPC_C respectively, then the concentrations shall be limited so that the following relationship exists:

$$\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\frac{C_C}{MPC_C}\leq 1$$

2. If either the identity or the concentration of any radionuclide in the mixture is not known, the limiting values for purposes of Appendix B shall be:

a. For purposes of Table I, Col. 1—6×10^{-13}

b. For purposes of Table I, Col. 2—4×10^{-7}

c. For purposes of Table II, Col. 1—2×10^{-14}

d. For purposes of Table II, Col. 2—3×10^{-8}

3. If any of the conditions specified below are met, the corresponding values specified below may be used in lieu of those specified in paragraph 2 above.

a. If the identity of each radionuclide in the mixture is known but the concentration of one or more of the radionuclides in the mixture is not known, the concentration limit for the mixture is the limit specified in Appendix "B" for the radionuclide in the mixture having the lowest concentration limit; or

b. If the identity of each radionuclide in the mixture is not known, but it is known that certain radionuclides specified in Appendix "B" are not present in the mixture, the concentration limit for the mixture is the lowest concentration limit specified in Appendix "B" for any radionuclide which is not known to be absent from the mixture; or

c. Element (atomic number) and isotope	Table I		Table II	
	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
If it is known that Sr 90, I 125, I 126, I 129, I 131, (I 133, table II only), Pb 210, Po 210, At 211, Ra 223, Ra 224, Ra 226, Ac 227, Ra 228, Th 230, Pa 231, Th 232, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	----------	9×10^{-9}	----------	3×10^{-6}
If it is known that Sr 90, I 125, I 126, I 129, (I 131, I 133, table II only), Pb 210, Po 210, Ra 223, Ra 226, Ra 228, Pa 231, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	----------	6×10^{-9}	----------	2×10^{-6}
If it is known that Sr 90, I 129, (I 125, I 126, I 131, table II only), Pb 210, Ra 226, Ra 228, Cm 248, and Cf 254 are not present	----------	2×10^{-9}	----------	6×10^{-7}
If it is known that (I 129, table II only), Ra 226, and Ra 228 are not present	----------	3×10^{-9}	----------	1×10^{-7}
If it is known that alpha-emitters and Sr 90, I 129, Pb 210, Ac 227, Ra 228, Pa 230, Pu 241, and Bk 249 are not present	3×10^{-9}	----------	1×10^{-10}	----------
If it is known that alpha-emitters and Pb 210, Ac 227, Ra 228, and Pu 241 are not present	3×10^{-10}	----------	1×10^{-11}	----------
If it is known that alpha-emitters and Ac 227 are not present	3×10^{-11}	----------	1×10^{-12}	----------
If it is known that Ac 227, Th 230, Pa 231, Pu 238, Pu 239, Pu 240, Pu 242, Pu 244, Cm 248, Cf 249 and Cf 251 are not present	3×10^{-12}	----------	1×10^{-12}	----------

4. If a mixture of radionuclides consists of uranium and its daughters in ore dust prior to chemical separation of the uranium from the ore, the values specified below may be used for uranium and its daughters through radium-226, instead of those from paragraphs 1, 2, or 3 above.

a. For purposes of Table I, Col. 1—1×10^{-10} μCi/ml gross alpha activity; or 5×10^{-11} μCi/ml natural uranium; or 75 micrograms per cubic meter of air natural uranium.

b. For purposes of Table II, Col. 1—3×10^{-12} μCi/ml gross alpha activity; or 2×10^{-12} μCi/ml natural uranium; or 3 micrograms per cubic meter of air natural uranium.

5. For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_A) to the concentration limit for that radionuclide specified in Table II of Appendix B (MPC_A) does not exceed 1/10 (i.e. $\frac{C_A}{MPC_A}\leq\frac{1}{10}$) and (b) the sum of such ratios for all the radionuclides considered as not present in the mixture does not exceed 1/4 (i.e. $\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\cdots\leq\frac{1}{4}$).

APPENDIX C

Material	Microcuries
Americium-241	.01
Antimony-122	100
Antimony-124	10
Antimony-125	10
Arsenic-73	100
Arsenic-74	10
Arsenic-76	10
Arsenic-77	100
Barium-131	10
*Barium-133	10
Barium-140	10
Bismuth-210	1
Bromine-82	10
Cadmium-109	10
Cadmium-115m	10
Cadmium-115	100
Calcium-45	10
Calcium-47	10
Carbon-14	100
Cerium-141	100
Cerium-143	100
Cerium-144	1
Cesium-131	1,000
Cesium-134m	100
Cesium-134	1
Cesium-135	10
Cesium-136	10
Cesium-137	10
Chlorine-36	10
Chlorine-38	10
Chromium-51	1,000
Cobalt-58m	10
Cobalt-58	10
Cobalt-60	1
Copper-64	100
Dysprosium-165	10
Dysprosium-166	100
Erbium-169	100
Erbium-171	100
Europium-152 9.2 h	100
Europium-152 13 yr	1
Europium-154	1
Europium-155	10
Fluorine-18	1,000
Gadolinium-153	10
Gadolinium-159	100
Gallium-72	10
Germanium-71	100
Gold-198	100
Gold-199	100
Hafnium-181	10
Holmium-166	100
Hydrogen-3	1,000
Indium-113m	100
Indium-114m	10
Indium-115m	100
Indium-115	10
Iodine-125	1
Iodine-126	1
Iodine-129	0.1
Iodine-131	1
Iodine-132	10
Iodine-133	1
Iodine-134	10
Iodine-135	10
Iridium-192	10
Iridium-194	100
Iron-55	100
Iron-59	10
Krypton-85	100
Krypton-87	10
Lanthanum-140	10
Lutetium-177	100
Manganese-52	10
Manganese-54	10
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m*	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	.01
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	.01
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
**Thorium (natural)[1]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
**Uranium (natural)[2]	100
Uranium-233	.01
Uranium-234—Uranium-235	.01
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	.01
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	.1

NOTE: For purposes of §§ 20.203 and 20.304, where there is involved a combination of isotopes in known amounts the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity"). Example: For purposes of § 20.304, if a particular batch contains 20,000 μCi† of Au^{198} and 50,000 μCi† of C^{14}, it may also include not more than 300 μCi† of I^{131}. This limit was determined as follows:

† $\frac{20{,}000\ \mu Ci\ Au^{198}}{100{,}000\ \mu Ci} + \frac{50{,}000\ \mu Ci\ C^{14}}{100{,}000\ \mu Ci} + \frac{300\ \mu Ci\ I^{131}}{1{,}000\ \mu Ci} = 1$

The denominator in each of the above ratios was obtained by multiplying the figure in the table by 1,000 as provided in § 20.304.

[1] Based on alpha disintegration rate of Th-232, Th-230 and their daughter products.
[2] Based on alpha disintegration rate of U-238, U-234, and U-235.
* Amended 36 FR 16898.
** Amended 39 FR 23990.
† Amended 38 FR 29314.

Appendix D

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IV Arkansas, Colorado, Idaho, Kansas, Louisiana, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, and Wyoming	Region IV, USNRC Office of Inspection and Enforcement 611 Ryan Plaza Drive Suite 1000 Arlington, Texas 76012	(817) 334-2841	(817) 334-2841
V Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington, and U.S. territories and possessions in the Pacific	Region V, USNRC Office of Inspection and Enforcement 1990 N. California Blvd. Suite 202 Walnut Creek, Calif. 94596	(415) 486-3141	(415) 486-3141

40 FR 42557

*Amended 41 FR 55851.

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2. No smoking
3. Gloves and
radionuclides.
4. Prescribed
5. Hands, sh
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6. Work with
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7. Radionucl
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8. Utilize shie
9. Dispose of
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10. Refrigera
used for stori
11. Monitor
daily for cor
survey in labo
12. Thorough
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2. No smoking
3. Gloves and
radionuclides.
4. Prescribed personnel monitors must be worn.
5. Hands, shoes and clothing should be frequently monitored.
6. Work with radioactive materials in an approved hood or glove box, unless the safety of working on an open bench can be demonstrated.
7. Radionuclide work should be conducted in an impervious tray or pan, lined with absorbent paper.
8. Utilize shielding and distance whenever possible.
9. Dispose of liquid and solid radioactive waste in the approved containers provided.
10. Refrigerators containing radionuclides shall not be used for storing food.
11. Monitor radionuclide work areas at least once daily for contamination and make notation of this survey in laboratory records.
12. Thoroughly wash hands after manipulating radionuclides, before eating or smoking, and on completion of work.
13. Maintain records of receipt, use, transfer and disposal of radioactive materials.

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